CHILLED BEAM SYSTEMS - A GREEN ENGINEERING SOLUTION FOR HVAC SYSTEMS

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ABSTRACT

With 'Green Buildings', designers have to explore ways to minimise energy consumption through passive means and tap renewable energy to operate building systems such as lighting and electrical appliances.

However, situations may require buildings to have a Heating, Ventilating and Air Conditioning (HVAC) system to maintain acceptable indoor conditions. Hence, it is necessary to use systems that are energy efficient, especially for high-rise and industrial buildings.

The objectives of this technical paper are:

- To explain what chilled beam systems are, how they operate and highlight their potential benefits and design pitfalls with suggestions on how to overcome these design challenges.

- To provide a brief review on existing chilled beam installations in South East Asia and current trends for chilled beam systems.

INTRODUCTION

Industrial complexes and high-rise buildings in cities often require air-conditioning system to maintain an acceptable indoor environment for process control purpose and thermal comfort respectively. HVAC systems generally recognised as environmental friendly for high-rise and industrial buildings may include:

a. Variable Air Volume (VAV) System
b. Under Floor Air Distribution (UFAD) System
c. Displacement Ventilation System

Variable Air Volume (VAV) System

To maintain indoor thermal comfort with VAV system, it conserves energy by varying the amount of supply air-conditioned into the occupied space to meet the desired cooling demand. This is usually achieved by means of variable frequency drive. As cooling load demand reduces, the fan speed will reduce proportionally but the energy consumed by the fan will reduce exponentially according to the Fan Law.

Under-Floor Air Distribution (UFAD) and Displacement Ventilation Systems

The Fundamental Handbook by the American Society of Heating, Refrigerating, Ventilating and Air-Conditioning Engineers (ASHRAE) categorised these systems as 'thermal displacement ventilation (TDV)' systems. Such systems are increasingly popular because "of their high contamination removal efficiencies and their possible energy savings[1]" and improve indoor air quality (IAQ). With such system, conditioned air is supplied at a low level within the occupied zone. This cooler and cleaner supply conditioned air will cascade across the floor. The supplied air will be drawn towards any heat source generated by the occupants and electrical equipment within the room. The air will then rise up with the plume of warm air whilst carrying any airborne contaminants above the occupied zone where it should be extracted and discharged outdoor.

WHAT ARE CHILLED BEAMS?

Chilled beam system utilises water as the medium to transport energy to cool down the room sensibly. This system is widely used in Europe for more than two decades since mid-1990s, followed by the United States, Australia and more recently China and India. According to a publication by HEVAC in the U.K., chilled beam and chilled ceiling systems are "generally regarded as the most space efficient and environmentally friendly method of heating and cooling a building.[2]"

It is important to note that chilled ceiling system operates quite differently from chilled beam system. The latter provides much more cooling output. There are two types of chilled beam in the market, 'passive beams' and 'active beams'. Both chilled ceiling and chilled beam systems have demonstrated to offer excellent thermal comfort condition with minimal risk of draught and known to consume less energy than conventional 'all-air' systems.

Figure No.1 below clearly shows that the cooling output from the chilled ceiling system is the lowest when compared to passive and active beams.

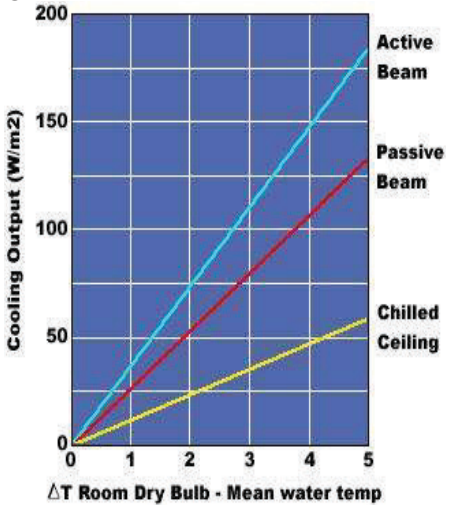
Chilled ceiling and passive beams are both 'all-water' systems. With such systems, it requires to have a

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separate supply air-conditioned system to provide adequate outdoor air and to cope with latent gain in the rooms.

Active chilled beams however utilise 'air-water' system with primary conditioned air supplied through the chilled beams. Active chilled beam systems offer the highest cooling output and hence, it is best suited for the tropics.

Figure No.1: Typical cooling output from chilled ceiling and chilled beams.



However, the rate of primary air supply to each room with chilled ceiling and beam systems in general is considerably lower compared to conventional 'all air' systems because it only needs to meet the minimum statutory fresh requirement, typically between 5 to 18 l/s per person. The primary supply air must be air-conditioned and supplied in sufficient quantity to keep the room relative humidity under control.

Chilled Ceiling System

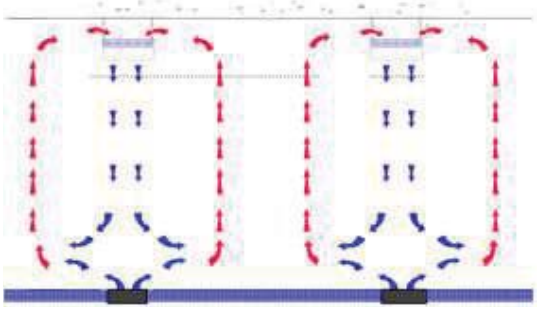
Chilled ceiling system utilises chilled ceiling panels to provide sensible cooling in the room by supplying chilled water to the panels. A separate primary supply air-conditioned system is required to provide adequate outdoor air and to deal with the latent gain within each room or zone. This normally introduced into the room at low-level using either displacement ventilation or UFAD system. Heat transfer from the chilled ceiling panels is dependent largely on radiation (i.e., between 55% to 70% depending on the beam design) and the balance by convection.

Typical cooling output from chilled ceiling system is normally between 60 to 80 W per m², which is lower than passive beams and active beams. Such a system is better suited in temperate climate.

Passive Chilled Beam System

Unlike chilled ceiling system, passive beams operate largely on convective forces. Warm air in the room will rise to high level above the occupied zone. When it comes in contact with the chilled beams, the warm air is cooled down thus creating a downward air movement directly below the beam due to negative buoyancy of the cool air relative to the surrounding air below the beams. (Refer to Figure No. 2 below)

Figure No. 2: Operation principle of Passive Beam



Passive beams are suitable for recessed mounting (i.e., installed behind suspended ceiling); flush mounted to the suspended ceiling or are completely exposed.

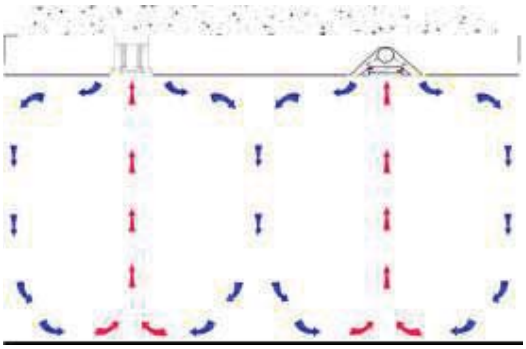
Location of the primary air outlets is important to prevent the supply air stream from crossing over the face of the passive beams. When this occurs, it affects the cooling output from the passive beams because it disrupts the convective air movement around the beams.

Active Chilled Beam System

Active chilled beam system is an 'air-water' system. The design concept of active chilled beam system is to maximise the sensible cooling from the chilled water coil and keeping the primary supply air to the minimal meet the minimum statutory requirement, typically between 5 to 18 l/s per person.

The active chilled beam discharges primary supply air at high velocity through the nozzles. This causes the induction of room air through the cooling coil and mixes up with the primary air before discharging into the room as shown in Figure No.3 below.

Figure No. 3: Operation principle of active chilled beam



Active chilled beams can be installed flash mounted to the suspended ceiling system or exposed as shown in Figure No. 8 for a project in Malaysia.

DESIGN CHALLENGES IN THE TROPICS

With chilled systems in humid weather condition as in the tropics, it is important to be able to control and maintain the relative humidity in the rooms, typically no greater than 55% during operation period.

Chilled beam system is suitable only in areas where relative humidity (RH) is under control to prevent condensation on the chilled beams. Restaurants and kitchens for example are not suited for such system because the anticipated latent gain is very high unless the relative humidity in the room can be controlled effectively with local desiccant drier or dehumidifier. To control the room RH, designer should consider adopting a combination of methods as listed below where appropriate:

1. Maintain a constant positive pressure in areas with chilled beam system to prevent infiltration of humid outdoor air.

2. Employ draft lobby at each main entrances to the building to prevent ingress of external humid air.

3. Supply conditioned air into the rooms during 'start-up' period in the morning to bring the relative humidity down to an acceptable level before the building is occupied. Once the room RH is under control, only then should the chilled beam system be set into operation. This is known as the 'start-up' period.

4. Install contact switches to windows that can be opened to outdoor in order to shut-off the chilled water supply to the relevant chilled beam section when humidity level suddenly increases when any of the windows is open.

5. Keep the chilled water supply temperature above room dew-point temperature. According to Martin and Alamdari, "a differential of 2K between the room dew point and chilled water temperature is generally considered realistic.[3]" In their report, Rumsey and Weale made similar recommendation that "chilled water needs to be supplied to the chilled beams at least 3 or 4 °F (i.e., 1.7 or 2.2 °C) above the room dew point[4]".

BENEFITS OF CHILLED BEAM SYSTEM

Research has shown that chilled beam systems can provide comfortable thermal environment. Using water as a medium to transfer energy instead of air enables the system to be more energy efficient. This is because water has a specific heat capacity that is about four times higher than air. Consequently, this reduces the operating cost of transporting energy from the central HVAC plant to the point of use and lower capital costs because the HVAC plant and ventilation ductwork that serve the chilled beams will be smaller. This means that the building floor-to-slab height can also be reduced (refer to Figure No. 4) since the depth of the ceiling void can be reduced accordingly to suit smaller ductwork. Chilled beam system also requires minimal maintenance and does not require spare parts since they have no moving parts compare to fan coil system for example.

For the same amount of cooling load as shown in the work examples given in Table 1 on the next page, the cross-sectional area of the ventilation duct ($\mathbf{A}_{duct}$) is about 300 times larger than the cross-sectional area of the chilled water pipe ($\mathbf{A}_{pipe}$) assuming that medium has the same temperature differential of 10°C. Hence, according to Dr. Guntermann "water requires only 5% of the pumping capacity (*or fan power consumption*) needed for air[5]."

Figure No. 4: Comparing floor-to-slab height requirement between conventional 'all-air' and chilled beam systems

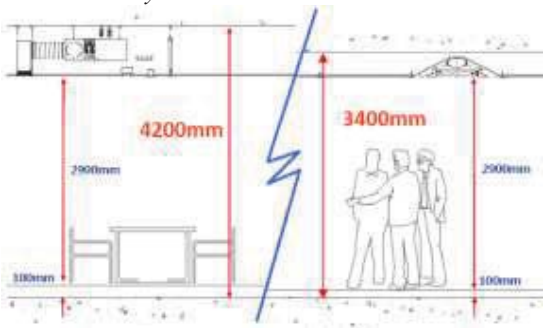


Table 1
Comparison between ventilation duct and chilled water pipe size.

Cooling Load (kW)	Supply Air; ΔT of 10 °C		Chilled Water; ΔT of 10 °C		Ratio A_{duct} to A_{pipe}
	Flow (l/s)	Duct size (mm)	Flow (l/s)	Pipe size (mm)	
1.0	83	175Ø	0.023	10 Ø	307
10.0	833	425Ø	0.238	25 Ø	290

Using 'all-air' system requires larger ductwork that is both bulky and requires more time and resources to install. It also requires larger vertical service shaft and duct fittings such as fire dampers, which takes up valuable floor space and is more costly.

In addition, chilled beams have fewer electrical and moving mechanical parts if compared to fan coil system for example. Thus, chilled beam system is quieter, requires less maintenance, lower inventory cost and is less likely to fail.

Table 2
Case study for an office building in the US by Alexander and O'Rourke[7].

ASHRAE Journal; Sep 2008	Conventional System (%)	Chilled Beam System (%)	% Reduction
Pump	0	1.4	-100.00
Fan motor	37.5	7.5	80.00
Lighting	18.8	9.4	50.00
Air transportation	9.3	1.9	79.57
Others	34.4	34.4	0.00
Peak Demand	**100**	**54.7**	**45.3**

Note: Conventional system is used as the baseline for comparison.

Numerous independent case studies have supported these findings just mentioned. For example, a report for an office building by Alexander and O'Rouke[7] (refer to Table 2); one on a laboratory centre by Rumsey and Weale[4] and another for a call centre by Weidner, Doerger and Walsh[8] have similar findings. These reports are available from ASHRAE publications, based on projects in the US. With this information, one may conclude that main potential benefits of chilled beam systems are:

a. Lower capital cost (i.e., building and M & E costs because of smaller plant and ductwork are required).
b. Lower installation cost.
c. Lower operating cost.
d. Lower maintenance cost.

Figure No.5: Typical aerodynamic profile of 2-way throw active chilled beams.



Separate studies have been done with mock-up tests conducted in aerodynamic test laboratory as shown in Figure No.5 above and using Computer Fluid Dynamic (CFD) analysis (refer to Figure No. 6 and 7) for chilled beam systems have indicated that air velocity and temperature profile within the occupied space are within accepted recommended comfort levels. It is important to note that the prerequisite for achieving the desired thermal comfort levels are:

a. The chilled beams are selected correctly to suit the design intend.
b. Installation arrangement including adequate spacing between chilled beams and from the adjacent walls and, mounting height of the chilled beams are important consideration for the designer. This should be in accordance with the chilled beam manufacturer's recommendations to achieve the desired Air Diffusion Performance Index (ADPI).

In the UK, David Butler[6] from the Building Research Establishment (BRE) conducted a study on chilled ceiling and chilled beam systems installed in four different buildings. He monitored the thermal comfort levels in each of these buildings throughout the summer of 1996 and found that:

a. The building occupants were very satisfied with the system installed and comfort level achieved.
b. The overall noise level from the system is low but some may find this to limit privacy of conversation.
c. The installation was perceived as being unobtrusive in appearance.

Figure No.6: CFD simulation of air velocity profile in a room with active chilled beam system.

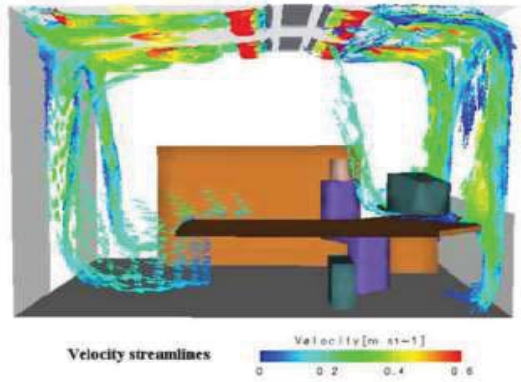
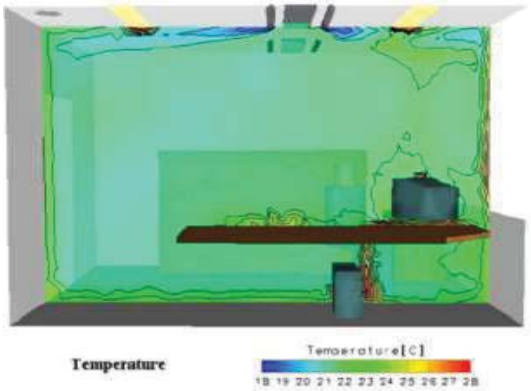


Figure No.7: CFD simulation of room temperature profile with active chilled beam system.



CHILLED BEAM SYSTEMS IN SOUTH-EAST ASIA

In South-East Asia where sensible heat gain in buildings is high, the choice of chilled beam system may be limited to active chilled beams. However, it may be possible to use passive chilled in internal zones if the internal sensible gain is not excessive.

However, if the fabric and solar heat gain is reduced significantly by improving the overall thermal insulation of the building envelope with external shading, it may be possible to use passive beams under such circumstances. To do so, it would necessitate the building design and construction method to take a very different approach compared to the norm in this region. As a result, construction cost may increase due to higher material and labour costs. Research data on energy savings and cost comparison for chilled beam systems in this region is currently not available. This is in spite of the fact that there are at least two known buildings in Malaysia and one in Singapore with chilled beam system in operation at least since 2012.

Based on qualitative assessment and customers' feedback for two of the installations that TROX have supplied chilled beams to (refer to Figure No. 8 and 9), it would appear that the building occupants for both buildings are satisfied with the thermal comfort condition and no condensation problem was reported after testing and commissioning (T & C).

As with all new technology, there were teething issues that require attention especially relating with condensation problem on the beams during T&C. But this can be attributed to inexperience and lack of understanding on the controls strategy for the chilled beam system before it was set correctly for T & C. However, once the operators become familiar with the system and knows what to look out for and avoid, the chilled beam system has since been working satisfactorily without condensation problem.

Figure No. 8: Installation example of an exposed active chilled beam at Manipal University, Malaysia.



Figure No. 9: Flushed mounted 4-way throw active chilled beams at Lanxess, Singapore.



CURRENT TRENDS FOR CHILLED BEAM SYSTEM

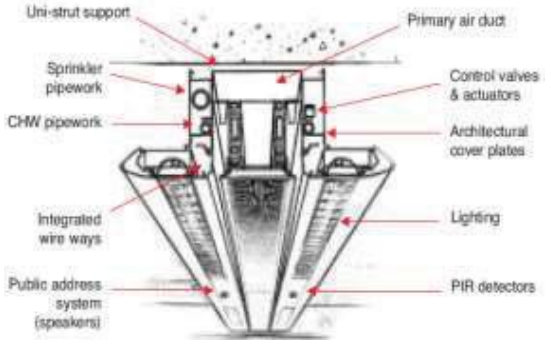
The latest trend in Europe and particularly in the UK is to integrate chilled beams with other mechanical and electrical (M & E) services to form 'multi-service chilled beams (MSCB)'. Such MSCBs can either be passive or active chilled beams. They can be installed flash to the suspended ceiling or exposed.

Multi-service chilled beams may include any or all of the following M & E services:

1. Fire protection system. This may include smoke and/or heat detectors, sprinkler system and/or audible or visual alarm.
2. Public Address (PA) system.
3. Electrical lighting system.
4. Close Circuit TV (CCTV) system.
5. Cabling systems for power, audio, controls and internet cables.
6. Hot water and chilled water pipework.

With MSCBs, the selected mechanical and electrical services commonly found installed on suspended ceiling system will require full integration with the design of the chilled beams at early design stage. The MSCBs are designed for 'plug-and-play'. They are manufactured as pre-fabricated units and are factory tested to ease site installation and testing (Refer to Figure No. 10 and 11).

Figure No. 10: Typical Multi-Service Chilled Beam



Since MSCBs are pre-fabricated and factory tested, the finished product should be better. As a result, installation and testing of these beams on site will take less time and delay due to adverse weather and/or unfavourable site condition is less likely to happen compared with the conventional method of installing and testing M & E services on site. Hence, this could save both time and money.

Figure No. 11: Installation example of exposed MSCBs in the Newcastle City Library, England.



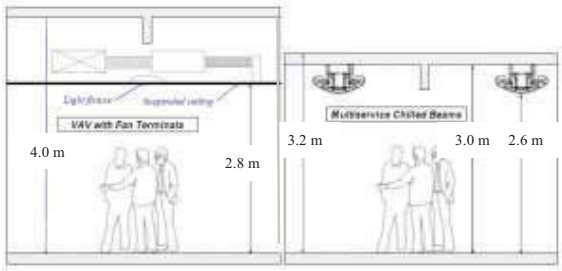
Other benefits of MSCB are:

• There will be no need to install suspended ceiling system with exposed chilled beams. MSCBs can be used as a special architectural feature in buildings. They have to be designed and made to meet specific architectural and engineering requirements. Thus, this requires close collaboration between the Architect, M & E Design Engineer and chilled beam manufacturer at early design stage.

• With exposed chilled beams, the slab-to-slab height could be reduced to as low as 2.8 m high. Thus, reducing floor-to-floor height, construction time and building costs. Figure No. 12 below shows a likely difference between VAV system and exposed multi-service chilled beam system in terms of floor-to-slab height requirement.

• Where there is a restriction on the building height by the local town planning authority, MSCB units including chilled beam systems will allow property developers and building owners to build one additional floor for every 7 or 8 floors with the same overall building height that is normally required for conventional 'all-air' HVAC system. This is because conventional 'all-air' system requires more ceiling void depth to accommodate larger ventilation ductwork as mentioned earlier.

Figure No. 12: Comparison on floor-to-ceiling height requirement between VAV and exposed multi-service chilled beam systems.



Like the standard passive and active beams, multi-service chilled beams may help reduce capital costs

and will certainly reduce installation, operating and maintenance costs.

Reputable multi-service chilled beam manufacturer should be included as part of the design team at early design stage in order to develop a suitable multi-service chilled beam that is aesthetically pleasant, user friendly and coherent with the overall design objectives.

CONCLUSION

To implement a chilled beam system successfully, it is important for the design team, installer and operator to have a clear understanding how it works regardless whether it is a passive or an active chilled beam system. With careful design and proper selection, planning and installation, chilled beam system is certainly a viable 'green' HVAC solution even in the tropics. Prevention of condensation is paramount to the success of any chilled beam system.

Numerous studies have been carried out on projects in Europe and the US. These studies demonstrate that chilled beam systems can reduce initial investment costs of building and operating costs (i.e., lower energy consumption and maintenance costs) compared to conventional 'all-air' HVAC systems whilst maintaining satisfactory comfort conditions.

The limited numbers of chilled beam installations that are currently in operation in Malaysia and Singapore have demonstrated that chilled beam system can provide satisfactory comfort condition in the tropics. There is no report of condensation problem after these systems have been fully tested and commissioned.

For unknown reason, information on energy and cost savings is not available or accessible to the public for the existing chilled beam installations in Malaysia and Singapore. It would be beneficial to conduct review and follow-up studies on these systems to gain a deeper understanding of its performance in the tropics. However, to do so and have the studies made available to the public such work should be funded by the relevant government agency or NGO.

Any mechanical and electrical services commonly found concealed in the ceiling void can be designed and integrated into the multi-service chilled beams. These MSCBs are pre-fabricated, factory tested and designed for 'plug-and-play' arrangement. Hence, MSCBs should offer better quality finish of the products and may reduce installation, testing and commissioning costs.

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SELECTIVE PLACEMENT OF VERTICAL AND ROOFTOP GREENERY

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ABSTRACT

The reduction in temperature due to the implementation of urban greenery has been well documented. However, the potential of greenery as a means of heat mitigation has not being fully realized, especially in the aspects of mean radiant temperature (t_{mrt}). This paper explores the possibility of selective placement of greenery for optimized cooling effect, by examining the results of two field studies conducted in Singapore. The first study looks at the cooling effect of green walls while the second study looks at how rooftop greenery can reduce temperature.

Both studies demonstrate the significant impact of urban greenery on diurnal t_{mrt}. The reduction in t_{mrt} for both cases can be correlated to variables such as exposure to solar irradiance. The rational for selective greenery placement can be justified using results from these field measurements.

INTRODUCTION

The cooling effect of greenery has been well-documented worldwide (Gao, 1993; Ca et al., 1998; Shashua-Bar and Hoffman, 2000; Jonsson, 2004; Wong and Chen, 2005). Recognising the positive impacts of urban vegetation, many governments have initiated policies aiming to improve the condition of the city through the addition of greenery (Beatley, 2000; Ra, 2006; Zhao, 2011). Urban greenery can be categorised in a variety of ways. Some examples include the Green Plot Ratio (GPR), which combines the concepts of Leaf Area Index (LAI) and Building Plot Ratio (BPR) (Ong, 2003). Park provision ratio and per capita green cover are urban planning benchmarks that have been used in countries such as Singapore (Tan et al., 2013). The provision of Urban Green Spaces (UGS) acts as urban lungs, helping to absorb pollutants and releasing oxygen, provide clean air, water and soil, cleansing the city's environment (Hough, 1984). The cooling effect exhibited by plants is a result of its metabolic processes, such as photosynthesis and evapotranspiration. The extent to which plants engage in these processes is directly related to the amount of green matter, usually found in the leaves of the plant (Jones, 1992).

For densely built-up cities that do not have sufficient land to provide for UGS, roof gardens and vertical greenery are often employed as alternative forms of green cover. Countries with a high population density such as Hong Kong and Singapore are characterized by their compact city form and land scarcity (Warwick, 1993; Ganesan and Lau, 2000). Rooftop and vertical greenery can provide multiple ecological and environmental benefits that are similar to UGS, without the need for ground level space. Singapore, for instance, has paid particular attention to maximising the available high-rise environment to create a 'Vertical Garden City', via the introduction of rooftop gardens, vertical greenery and sky terraces (Tan, 2012).

Many studies have been conducted to quantify the benefits of vertical and rooftop greenery. Most of the studies focus on temperature reduction (Wong et al. 2003; Cheng et al., 2010; Perini et al., 2011). Vegetation can reduce the impact of the Urban Heat Island (UHI) effect by shading heat-absorbing surfaces and cooling the air through evapotranspiration (McPherson, 1994). The surface temperatures of vertical greenery systems have been observed to be cooler than common building materials such as light-coloured bricks, walls and black surfaces (Bass and Baskaran, 2003). This reduction of surface temperature can lead to a lower cooling load for the building interior (Wong et al. 2009; Pérez et al., 2011). Research into green roofs often focuses on the quantification of roof surface temperature. There are also studies into various aspects of rooftop greenery such as the types of plants used, growth substrates, acoustic performance, air quality and maintainability (Akbari, 2002; Parizotto and Lamberts, 2011; Baik et al., 2012; Saadatian et al., 2013). Various feasibility studies have also been conducted to determine structural and logistical considerations for green roof implementation (Castleton et al., 2010).

The reviewed literature suggests that most studies on vertical and rooftop greenery tend to focus on the reduction in surface temperature and cooling load. There is a knowledge gap on how the implementation of vertical and rooftop greenery will affect the outdoor thermal environment beyond the rudimentary understanding of a general decrease in temperature. This is much more pertinent to green roofs, as they are often designed as roof gardens and can be used as outdoor social spaces.

The evaluation of thermal environments can be done via comfort or heat stress indices (Fanger, 1972; Epstein and Moran, 2006), and often requires the measurement of the air temperature, mean radiant

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temperature, air velocity and relative humidity. The mean radiant temperature (t_{mrt}) can be considered to be one of the main factors contributing to both indoor and outdoor thermal comfort, as indicated in previous studies validating the relation between thermal comfort and shortwave and long wave radiation fluxes from the surroundings (Mayer and Höppe, 1987; Mayer, 1993).

This study seeks to assess the effects of vertical and rooftop greenery on the mean radiant temperature, as well as to explore the possibility of objective landscape design based on the cooling potential of both forms of greenery in the tropical urban environment.

METHODOLOGY

Two separate studies are conducted to measure the effects of vertical and rooftop greenery on t_{mrt}.

1. Measurements for vertical greenery

Two sets of data are derived. The first set of data consists of t_{mrt} collected from two green walls (Green Wall A and Green Wall B). Green Wall B is then removed and the second set of data consists of data of only green wall A and the exposed concrete wall that was Green Wall B. Estimation of mean radiant temperature (t_{mrt}) is conducted in front of the green walls. Properties of the two green walls are shown in Table 1.

Table 1
Properties of Vertical greenery systems

	GREEN WALL A	GREEN WALL B
SYSTEM	Suntory Midorie System	Shimizu Parabienta System
DIMENSIONS (H X W)	2.27 m X 1.90 m	3.18 m X 2.40 m
PLANTS USED	Piper sarmentosum Philodendron Cordyline terminalis Schefflera	Hemigraphis alternata Portulaca grandiflora Nephrolepis acutifolia
LAI	3.8	3.5

The t_{mrt} in front of the green walls is estimated up to 2.0 m away at intervals of 0.5 m. The sensors are approximately 1.7 m above ground. The two green walls have similar dimensions and plant carrier system but consist of different plant types. The LAI of both green walls is calculated by removing a 0.1 m by 0.1 m segment of the green wall, measuring the total leaf area size with a flatbed scanner and extrapolating it to the size of the green walls. Close-circuit television is used to monitor the effects of shading on estimated t_{mrt}. Field measurements are conducted on the roof top of the School of Design and Environment (SDE) Block 2 at the National University of Singapore (NUS), Singapore. Measurements are conducted from 27th September 2011 to 13th March 2012. The measurement period is further elaborated into Period A and B, where Period A denotes the measurement of both green walls, and Period B denotes measurement with Green Wall B removed (Table 2). Only clear and sunny days are used for analysis. Selection is based on solar irradiance data measured on-site with a pyranometer. Measurements are made at one minute intervals and averaged to hourly intervals for analysis.

Table 2
Measurement period

PERIOD	NO. OF DAYS USED FOR ANALYSIS	PURPOSE
A	5	Measurement for Green Wall A and Green Wall B
B	9	Measurement for Green Wall A. Green Wall B is removed

2. Measurements for rooftop greenery

A total of 28 points are set up for t_{mrt} measurement. Each measurement point, which consists of a customised globe thermometer fixed at 1.7 m above ground and an air temperature sensor housed in a PVC pipe, is secured with a concrete footing. The measurement points are aligned and named as shown in Figure 1.

The experiment is conducted at the NUS SDE1 rooftop. The t_{mrt} of six plots are measured. Each plot has a dimension of 3.0 m by 3.0 m. The first four plots are plots with vegetation. The fifth plot is covered with an acrylic sheet painted with cool paint. The sixth plot is bare concrete roof, used as a control for the measurement. The characteristics of each plot are shown in Table 3.

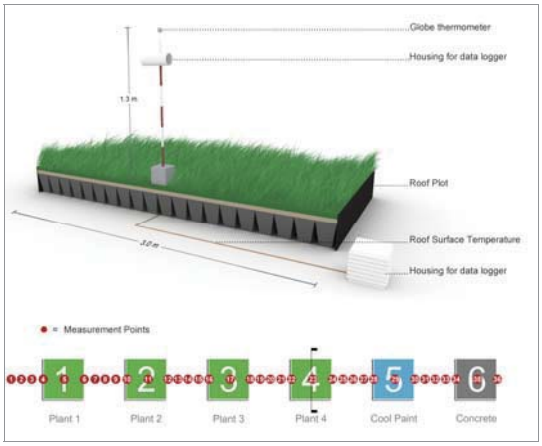


Figure 1 Measurement points and sectional perspective of roof garden setup

The Leaf Area Index (LAI) of plants, which is defined as the single side leaf area per unit ground area is measured in this experiment (Watson, 1947). Studies have shown a significant correlation between plant LAI and the corresponding rate of evapotranspiration (Mahdi et al. 1989; Stav and Lawson, 2012). As the rate of evapotranspiration rises, more solar radiation is converted into latent heat, thus reducing the ambient temperature.

Table 3
Plot characteristics for rooftop garden

Plot	Characteristic	Specification
1	Shrub	Phyllanthus cochinchinensis
2	Shrub	Heliconia American Dwarf
3	Shrub	Sphagneticola trilobata
4	Turf	Cow grass
5	Cool Paint	*JOTUN* Jotashield extreme
6	Concrete	Control

Each plot is placed at regular intervals of 3.0 m to minimize interference from neighbouring plots. Sensors are deployed to measure the t_{mrt} of all plots. Measurement is made at one minute intervals. A total of 42 sensors are deployed. Each globe temperature sensor is attached to a survey pole and measure t_{globe} at 1.3 m above the plots. Six sensors are placed underneath each plot to measure the roof surface temperature.

Estimation of t_{mrt} can be done using the globe thermometer (Vernon, 1932). Initially developed for indoor usage, the globe thermometer has since been adapted for outdoor use (Nikolopoulou and Lykoudis, 2006). The Vernon globe is a 150 mm diameter copper sphere painted black with a thermometer positioned in the middle of the sphere. For outdoor measurement, the 38 mm globe thermometer is a common option as the globe used is a table tennis ball, which can be readily purchased and conveniently replaced (Humphreys, 1977). The accuracy of the 38 mm globe thermometer can be adjusted to cater to outdoor conditions by recalibrating the mean convection coefficient (Thorsson et al., 2007). In this study, t_{mrt} is estimated using the following formula specifically calibrated for tropical outdoor use (Tan et al., 2013):

(1)

$$t_{mrt} = \left[(t_g + 273.15)^4 + \frac{3.42 \times 10^9 V_a^{0.119}}{\varepsilon D^{0.4}} \times (t_g - t_a)\right]^{0.25} - 273.15$$

t_g = Globe temperature (°C)
V_a = Air velocity (ms^{-1})
t_a = Air temperature (°C)
D = Globe diameter (mm)
ε = Globe emissivity

RESULTS AND DISCUSSION

1. Results for vertical greenery

Measurement points are aligned and named as shown in Figure 3. Five time ranges are used for analysis (Table 4).

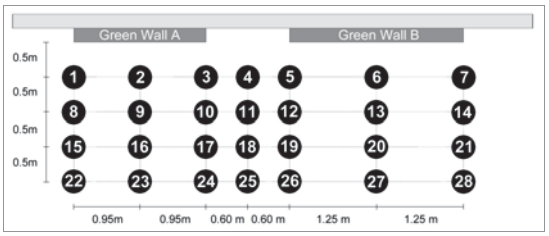


Figure 3 Position of t_{mrt} measurement points

Table 4
Time range used for analysis

Time Range	Period	Condition of wall
1	00:00 hrs – 07:00 hrs	Night to Sunrise
2	07:00 hrs – 14:00 hrs	Self-shaded
3	14:00 hrs – 17:00 hrs	Exposed to direct sunlight
4	17:00 hrs – 19:00 hrs	Overshadowing from trees
5	19:00 hrs – 00:00 hrs	Sunset to night

Profile of t_{mrt} across Measurement Points 1 to 7

The t_{mrt} profiles for Period A for Measurement Points 1 to 7 are shown in Figure 4. It can be observed that a portion of the readings near the bottom does not deviate significantly across the 7 points (19:00 hrs to 07:00 hrs). As the sun rises to its zenith, the average t_{mrt} increases steadily, and the difference between the 7 points begin to exhibit increasing amounts of deviation.

A distinct pattern is observed from 15:00 hrs to 17:00 hrs, where most readings peak at Point 4. This pattern exhibits itself most evidently at the highest recorded t_{mrt} at 15:00 hrs. A comparison with Figure 3 shows that Point 4 is the spot that is closest to the part of the wall that is exposed to direct sunlight, whereas the other points are covered with Green Walls A and B. This pattern diminishes significantly until the fluctuations cease from approximately 21:10 hrs onwards.

The same patterns are observed for Period B. However, higher peak readings are recorded. This is expected, as there is more concrete surface that is exposed to direct sunlight for Period B. Measurements of Points 5 to 7 are also higher than in Period A during Time Range 3. The difference in t_{mrt} value is clearly only significant during Time Range 3 (14:00 hrs – 17:00 hrs). Outside of this time range, the difference in t_{mrt} between Points 1 to 7 is minimal.

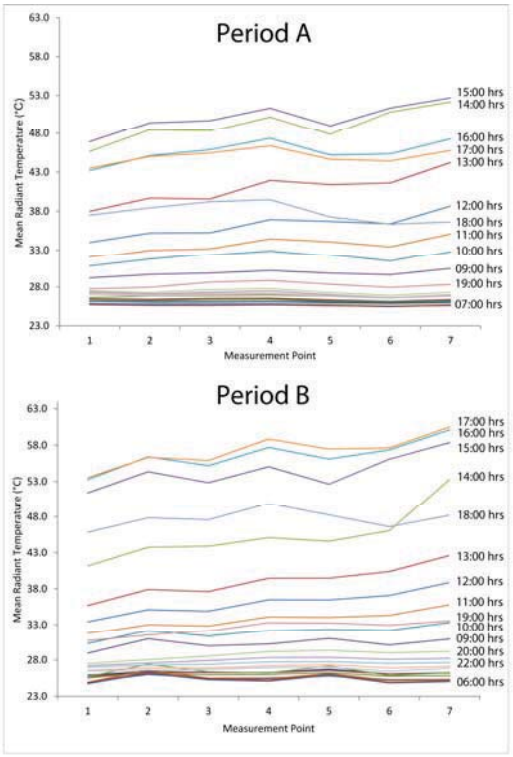


Figure 4 Comparison of t_{mrt} profile for Points 1-7 for Period A and Period B

Profile of t_{mrt} for Points 2, 4 and 6

The diurnal t_{mrt} profile is compared with the corresponding solar irradiance profile. Figure 5 shows the diurnal t_{mrt} plots across Points 2, 4 and 6 for Period A and Period B. Time Ranges 1 and 5 show no relation between the t_{mrt} profile and solar irradiance (due to the absence of sunlight). Time Range 2 shows an increase in t_{mrt} with solar irradiance. Similarly, Time Range 4 shows a similar trend, with t_{mrt} decreasing with solar irradiance correspondingly. It can be seen that the t_{mrt} values correspond to fluctuations of direct and intense solar irradiance (Time Range 3). More importantly, the largest differences in t_{mrt} for the different points occur during periods of peak solar irradiance. In other words, t_{mrt} in front of the Green Walls is reduced during periods of peak solar irradiance.

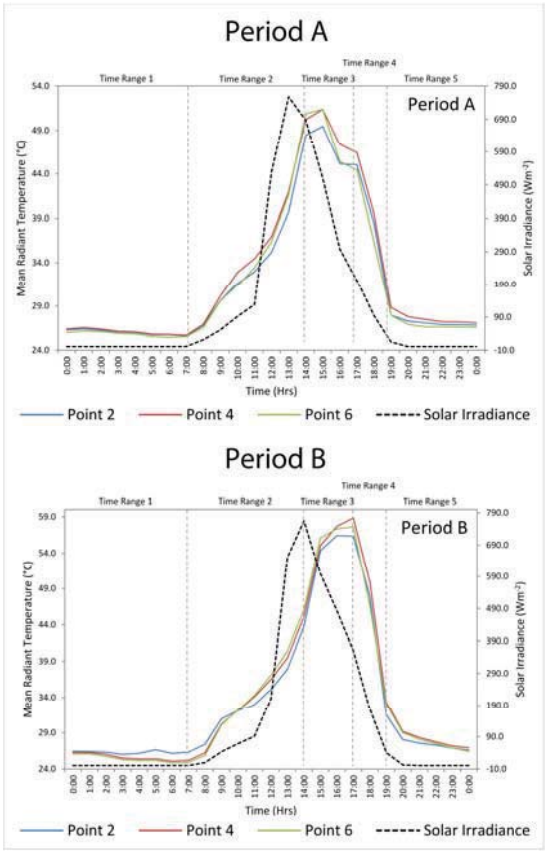


Figure 5 Plot of Points 2,4 and 6 against solar irradiance for Period A and Period B

Similar to Period A, Time Range 1 and the later part of Time Range 5 for Period B show no relation between the t_{mrt} profile and solar irradiance (due to the absence of sunlight). Time Range 2 shows an increase in t_{mrt} with solar irradiance. Similarly, Time Range 4 shows a similar trend, with t_{mrt} decreasing with solar irradiance correspondingly. It can be seen from Time Range 3 that the t_{mrt} values reach their peak at approximately 17:00 hrs, and it does not correspond to the solar irradiance peak to the likes of Period A. Exposure to increased concrete surface area may have resulted in a delay of the diurnal t_{mrt} peak. Increased longwave radiation may have been emitted by the exposed wall surface, resulting in the time lag.

Visualisation of t_{mrt} using Geographical Information Systems (GIS)

All 28 points are used for data interpolation using GIS. This enables quick analysis of the conditions of the surveyed area. Hot spots can be identified easily with this method. Measurements for a typical clear sunny day are used for visualisation via GIS. Figure 6 shows the t_{mrt} map of selected timings from 15:55 hrs to 00:35 hrs. It can be seen that the hot spot (dotted circle), which corresponds to Point 4, has a significantly high value compared to the rest of the points. This trend can be observed until approximately 00:00 hrs, although the magnitude of the difference differs drastically across different timings.

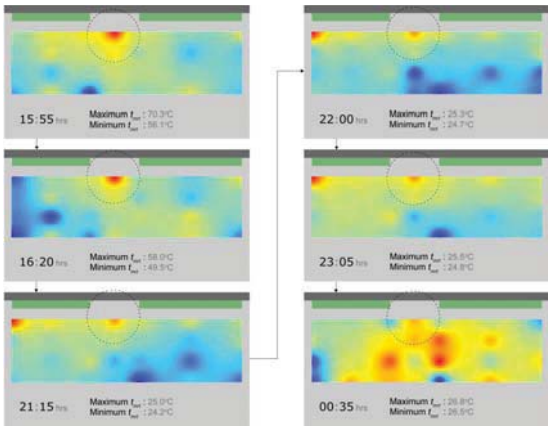


Figure 6 GIS visualisation of t_{mrt}

2. Results for rooftop greenery

Profile of t_{mrt} across rooftop greenery

The diurnal t_{mrt} profile for measurement points at the centre of the plots are plotted (Figure 7). The maximum and minimum values of t_{mrt} recorded are 63.0 °C and 24.9 °C respectively. The maximum difference during the hottest time (14:00 hrs) is approximately 6.0 °C. It is observed that Plots 4, 5 and 6 exhibit similar t_{mrt} profiles, peaking at approximately 63.0 °C. Of the six plots, Plot 1 (Phyllanthus cochinchinensis), has the lowest diurnal t_{mrt} profile, followed by Plot 2 (Heliconia American Dwarf) and Plot 3 (Sphagneticola trilobata). In the absence of sunlight (01:00 hrs – 07:00 hrs and 19:00 hrs to 00:00 hrs), the t_{mrt} profile for all six plots remain stable without much fluctuation.

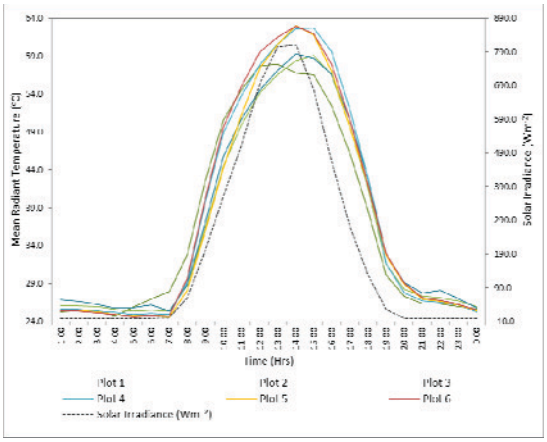


Figure 7 Diurnal t_{mrt} profile for clear sky conditions

Reflectivity test

Material reflectivity is measured using a spectrometer and the results are shown in Figure 8. Under the visible light spectrum, which spans from approximately 380 nm to 700 nm, cool paint exhibits the highest reflectivity of more than 80.0 %. This is followed by concrete with a peak reflectivity of 40.4 %. Vegetation under visible light displays relatively lower reflectivity, peaking at 25.2 % (Plot 4), 21.6 % (Plot 3), 14.5 % (Plot 1) and 13.8 % (Plot 2) at around 550 nm.

For wavelengths in the near-infrared range (700 nm to 2500 nm), the reflectivity of cool paint reduces gradually, while the reflectivity of concrete increases at a similar pace. The reflectivity of the plants increases significantly from 700 nm to 1400 nm and undergoes a series of fluctuations, rising again from 1600 nm to 1800 nm and 2200 nm. It can be seen that the reflectivity of plants from the range of 701 nm to 1300 nm can equal that of cool paint.

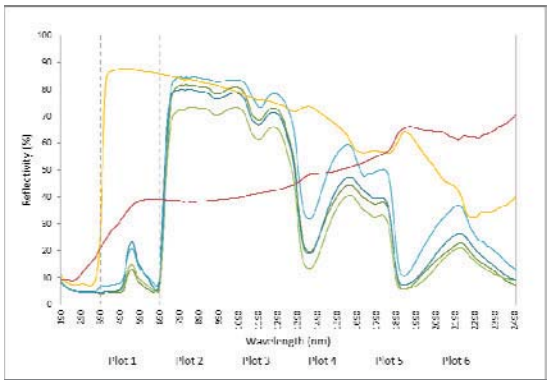


Figure 8 Spectrometer test results

Results show that when cool roofs and green roofs are exposed to direct solar irradiance, the surface temperature is significantly lower compared to the exposed concrete roof. However, only green roofs provide a substantial reduction in air and mean

radiant temperature. At peak temperature, air temperature 1.3 m above the cool roof can reach up to 32.9 °C, which is 1.0 °C higher than Plot 1. A possible reason for the lower air and mean radiant temperature experience by Plots 1 to 4 may be due to the evapotranspiration of plants. The presence of moisture in the soil and emancipation of water from the plant stomata increases the latent heat of vaporization and cools the surrounding air. Besides lowering the t_a and t_{mrt}, the introduction of green roofs can also help to minimize temperature fluctuations. Fluctuations in radiant temperature will drastically change the solar radiation absorbed by an individual and the energy budget of the person, affecting the overall thermal comfort.

Results from the reflectivity test shows that for the visible light range (380 nm to 700 nm), the cool roof can have a reflectivity of more than 80 %. In comparison, the reflectivity of plants is in the range of 20%, which is rather low. However, at the near-infrared range, especially from the range of 700 nm to 1400 nm, the reflectivity of plants can almost equal that of cool paint (Figure 8). Since up to 50 % of the solar irradiance distribution is in the near-infrared zone, this attribute may be crucial for reflecting heat back to the atmosphere. The high reflectivity of plants, in addition to the inherent cooling potential through evapotranspiration, may be the main factors leading to significantly lower t_s, t_a and t_{mrt} values.

CONCLUSION

The purpose of this study is to study the effects of vertical and rooftop greenery on the temperature of the outdoor environment. Results from both measurements have shown that temperature can be reduced significant by the employment of greenery under specific conditions.

For vertical greenery, surface temperature measured behind the green walls show that the green wall can reduce the surface temperature of the building envelope. This effect is not restricted to areas covered by the green wall; areas in close proximity to the green wall can also experience a reduction in surface temperature. The implementation of green wall helps to reduce fluctuations of surface temperature. The removal of Green Wall B only resulted in a slight increase in air temperature. However, there is significant difference in the t_{mrt}, especially within 1 m of the green walls. The maximum increase in t_{mrt} after the removal of Green Wall B is 12.8 °C. When one green wall is removed, the effect of time lag can be observed. The peak readings in t_{mrt} are delayed for approximately 2 hours.
It is important to note that while the implementation of vertical greenery can lower the t_{mrt} of its surroundings, this attenuation is evident for up to 1 m away from the wall. However, this lowering is effective only during periods of intense direct solar exposure. The effect is minimal during times when the green walls experience self-shading or overshadowing. Consideration should be made to the placement of vertical greenery to ensure maximum exposure to direct sunlight so as to take advantage of its t_{mrt} reducing attributes.

The use of GIS for data visualisation enables convenient visual comparison between t_{mrt} profiles of different timings. The interpolated values serve to provide a method to assess the t_{mrt} of any given space that is easily comprehensible to architects and planners. From the figures, it is evident that vertical greenery facilitated the reduction of t_{mrt} both in the day and at night, to varying magnitudes.

Results for the rooftop greenery measurements show that on clear sky conditions, the plots with vegetation can reduce the surrounding t_{mrt} by up to 6.0 °C. Reduced fluctuation in diurnal t_{mrt} is also observed for the plots with vegetation. The effect in temperature reduction is evident up for to 3.0 m away from the centre of the green plots. As the temperature reduction potential of plots require substantial solar insolation, roof gardens would also do well to be strategically sited in areas with exposure to direct solar radiation for maximum cool effect.

Findings from this study support the notion that plant selection and placement for landscape design can transcend beyond aesthetic requirements. The temperature reduction potential of each type of vegetation varies according to their physical characteristics and possibly, the rate of evapotranspiration. Direct measurements of LAI show that although Phyllanthus cochinchinensis and Sphagneticola trilobata used in the experiment have lower LAI values and smaller physical dimensions, both plants show significant reduction in temperature, which is likely to be due to their higher evapotranspiration rate. Both plants are also observed to have thick foliage and possess a physical form that allows for its leaves to spread and cover the bare soil as they propagate.

Effects of shading provide the optimal form of t_{mrt} reduction. Areas that do not have access to shade may consider the utilization of green walls and green roofs strategically placed to provide further reduction to t_{mrt}. Results from the two studies show that for the cooling potential of vertical and rooftop greenery to be realised, a minimum provision of sunlight is necessary.

The study argues for the selective placement of vertical and rooftop greenery by first exploring the avenue of sunlight provision. This can be accomplished via numerical simulation of solar

irradiance (Figure 9). Areas with adequate exposure to sunlight should be given priority for the addition of greenery. This can optimise resources and ensure adequate plant health.

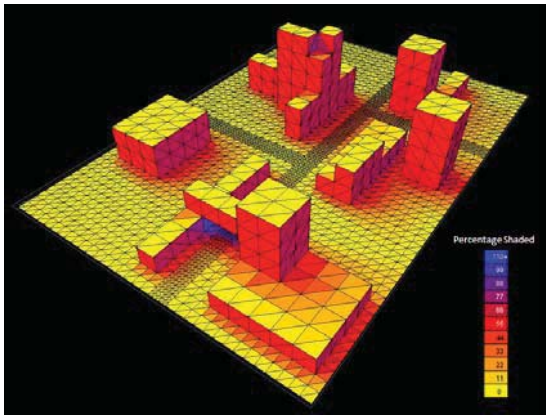


Figure 9 Greenery placement based on solar irradiance availability

Vertical and rooftop greenery are common staples in the design palette of architects and designers. This study has shown that in addition to aesthetic requirements, landscape design can also be optimized for heat reduction. The strategic placement of urban greenery can improve outdoor thermal comfort and enhance the quality of the built environment.

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NUMERICAL STUDY OF A CONCRETE CORE TEMPERATURE CONTROL (CCTC) BUILDING FOR TROPICS

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ABSTRACT

In this paper, we investigated the performance of a specific type of radiant cooling system - Concrete Core Temperature Control (CCTC). The performance of the CCTC was measured in terms of indoor occupant comfort and annual energy consumption using transient thermal simulation models. The results were compared to a conventional cooling and ventilation system. Annual weather data of Singapore and heat load of a typical office were created to simulate the hypothetical building with and without CCTC using Transient System Simulation (TRNSYS) software. Variable conditions such as flow rate of the cooling water, and mass of concrete were considered during the simulation exercise. It was found that, while achieving the same indoor comfort level, the building with the CCTC system was able to achieve significant energy savings at the chiller plant and air-distribution levels. The percentage reduction for electricity consumption in air distribution and in chiller was about 30% and 20%, respectively.

INTRODUCTION

Due to the hot and humid weather conditions in Singapore, air conditioning is widely used in buildings. In most cases, the air conditioning system consumes up to 50% of the total electricity consumption. One of the biggest challenges in achieving energy efficiency in buildings is to achieve a good indoor comfort level, while reducing the amount of energy consumed by air conditioning. One possible solution is radiant cooling systems; a high temperature cooling system that transports cooling energy to the building space through water, which is a more efficient heat transfer agent compared to air. Concrete Core Temperature Control (CCTC) is the practice of pumping cooling water through polymer pipes that are embedded in concrete of the building mass. The CCTC system makes use of the concrete mass as a heat sink for the internal heat load in the building, hence cooling the building space. Originated in Europe and popular in temperate climates around the world, CCTC is yet to be validated and implemented in buildings in the tropics.

A radiant floor cooling/heating system transports energy by water which is a more efficient way compared to an air system due to larger heat capacity of water (Olesen, 2008). Monte (2000) studied the transient response of one-dimensional multi-layered composite conducting slabs to sudden variations of the temperature of the surrounding fluid, applying the method of separation of variables to the heat conduction partial differential equation. Lu and Tervola (2005) analysed a novel analytical approach to heat conduction in a composite slab subject to periodic temperature changes. The solutions for partial heating of rectangular solids are reported by Beck et al. (2004) and methods of separation of variables and time-partitioning were also analysed. Laouadi (2004), developed two-dimensional prediction model for radiant systems for integration in energy simulation software, and the model is validated using the numerical modelling approach. heat transfer in thermally activated building constructions using both simplified star network and triangular network are reported by Weber and Johannesson (2005). Holopainen et al. (2007), examines the use of an uneven nodal network in floor heating simulation with finite difference heat balance method, and shows the benefits of placing the densest gridding in steepest curvature of the temperature gradient. Larsen et al. (2010), develops 2-D transient solution of a slab with an embedded array of parallel circular pipes. Jin et al. (2010), builds a numerical model of radiant floor cooling system using finite volume method with composite grids, and shows the pipe has effect on the performance when the thermal conductivity of the pipe is low and the effect of the water velocity on the performance is not great.

SYSTEM DESCRIPTION

The cooling of office and management buildings with environmental energy from soil, groundwater and air are energetically and economically particularly interesting. Especially in today's office buildings, thermal comfort plays an increasingly larger role. Conventional ventilation and air-conditioning cooling systems require very low water temperatures (forward / reverse; 8°C/12°C) in fan coil units and are therefore not particularly interesting for the use of

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environmental energy. They need a conventional compression refrigeration system to supply these low temperatures to fan coil units. The thermal concrete core activation provides a much more favourable approach here: Water-carrying pipe systems for year-round temperature control of buildings over a large area integrated within solid components (concrete floors and concrete ceilings) with high heat storage capacity. With the circulation of water into solid components, these components are loaded with cold or heat energy depending on the flow temperature. Unlike the familiar 60 mm screed with a conventional under floor heating system the concrete core activation has a significantly higher heat loading potential. Due to activated building material, the thermal heat load is shifted. Today this effect can be seen in old buildings like churches or castles that were built with very thick outer walls without interior lining. These buildings always maintain a pleasant cool indoor room temperature even at high outside temperatures. As a result of the large heat transfer area, the system allows for slight over or under temperatures in comparison to the indoor air temperature, significant heating or cooling capacities. The pipe network for the concrete core activation is usually made out of polyethylene or aluminium multi-layer composite pipes with diameters of 16-20 mm (Figure 1). For installation, cable ties are used. Besides the exact mounting of the pipes, a precise hydraulic balance is an important point. For the only, way to ensure that water is uniformly distributed in all circuits a precise and high quality water distributor is required. Another important point is the energetic structure of the object. In recent decades, architects and designers have attached high importance to the primary energy consumption of buildings. Therefore, thermally very tight building envelopes with the resulting low U-values have been created. Because of the flow temperatures being nearly equal to the room temperatures (as opposed to a conventional refrigeration system), it is not possible to counteract extreme peak loads. Due to this, problem planners and architects need to take great care especially of the building's sun protection.

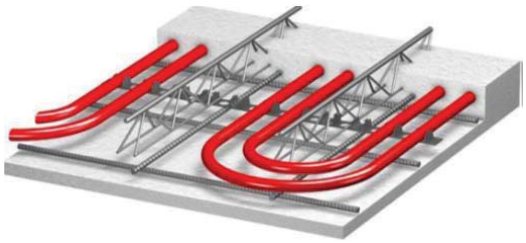


Figure 1: 3-D rendering of CCTC pipes embedded in concrete.

MODELLING AND SIMULATION

The purpose of using an energy-modelling tool, Transient System Simulation (TRNSYS) software, for this paper was to predict the behaviour of the CCTC system, as accurately as possible under different scenarios. Google Sketch-up Pro was used to create 3-D models of building spaces and fed into TRNSYS. After the building's 3-D geometry, zoning and construction types were defined and transferred to TRNBuild. Figure 2 and 3 is showing the simulation schematic for the building simulation and energy system in a building.

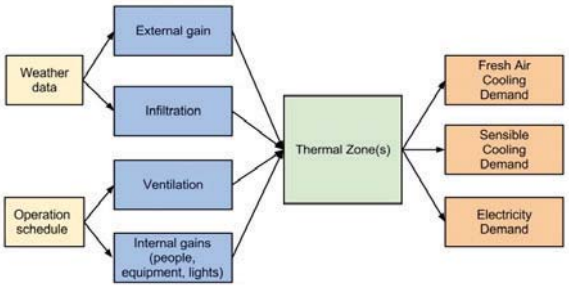


Figure 2: Simulation schematic for the building simulation.

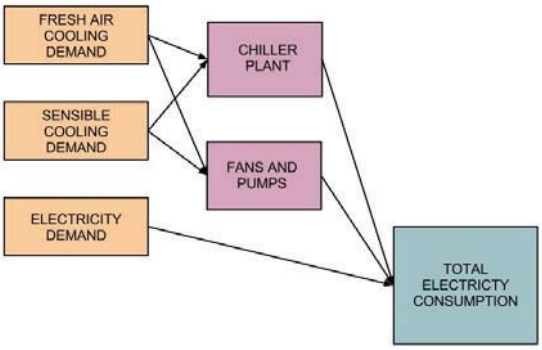


Figure 3: Simulation Schematic for the energy system in a building.

Two building spaces were modelled and simulated to measure the effectiveness and performance efficiency of the CCTC system. The Base Case (BC) is a building space with all the below mentioned parameters, without the CCTC system. In other words, it uses a conventional VAV system to handle the cooling and dehumidification requirements of the space(s). The Proposed Design (PD) has the same experimental parameters as the base-case, except that instead of cooling the space using the VAV system, part of the sensible load is handled by the CCTC system. Table 1 describes the input parameters that were used to create the building geometry and model and simulate the energy systems. The schematic and dimension of CCTC pipes embedded in concrete is shown in Figure 4. To model a radiant cooling CCTC, an "active layer" added to the wall, floor or ceiling definition. The layer is called "active" because it contains fluid filled pipes that remove heat from the surface. The active layer is described by five parameters:

- Specific heat coefficient of fluid in the pipes
- Pipe spacing
- Pipe outside diameter
- Pipe thickness
- Pipe wall conductivity

Table 1: Thermal Modeling parameters (System and Zone)

NO	PARAMETER	VALUE		UNIT
		BC	PD	
GEOMETRY				
1	Area	100	100	Sqm
2	Volume	300	300	Qm
3	Total Window Area	18	18	Sqm
LOADS				
4	Infiltration Rate	0.15	0.15	ACH/HR
5	People	25	25	--
6	Plug Load	1600	1600	W
7	Lighting Load	700	700	W
ZONE SET-POINTS				
8	Zone Temperature Set-point	23	23	C
9	Zone Relative Humidity Set-point	65	65	% RH
AIR-HANDLING UNIT SPECIFICATIONS				
10	Fresh Air Requirement	56	56	L/S
11	Fresh Air Temperature Set-point	20	20	0C
12	Fresh Air Relative Humidity Set-point	40	40	% RH
13	Fan Efficiency	0.45	0.45	W/CMH

For surfaces containing an active layer, the convective heat transfer coefficient between surface and zone air depends on the temperature of the active layer. Heat transfer coefficients depend heavily on the temperature difference between surface and fluid and the direction of heat flow. For example, the flow pattern evolved by a CCTC ceiling/floor is completely different to that of a vertical surface. The mathematical formula used for appropriate heat transfer coefficients is of the form;

$$\alpha_{conv} = const\left(T_{surf} - T_{air}\right)^{exp}$$

For horizontal surfaces, the convective heat transfer coefficient due to the difference between the surface temperature and the temperature of the air right near the surface calculated by

$$\alpha_{conv} = 2.11\left(T_{surf} - T_{air}\right)^{0.31}$$

The above relationship is valid assuming that the surface temperature is higher than the surrounding air temperature. If this is not the case, then the relationship given by

$$\alpha_{conv} = 1.87\left(T_{surf} - T_{air}\right)^{0.25}$$

where;
α_{conv} = Convective heat transfer coefficient; T_{surf} = Surface temperature; T_{air} = Air temperature

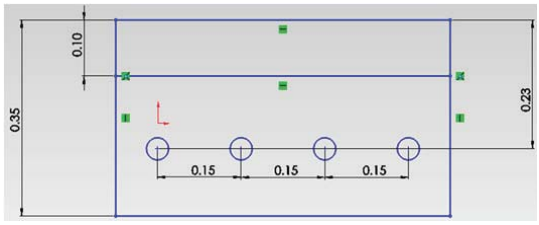


Figure 4: Schematic of CCTC pipes embedded in concrete

A specific minimum mass flow rate is necessary to assure that a linearization of the exponential curve between inlet and outlet temperature is possible. In most common cases, the specific mass flow rate has to be greater than 13 kg/hm² (the exact value is calculated for each active Layer). Therefore, two segments in series for most cases can model an ordinary piping system. The thickness of both layers adjacent to the active layer must be ≥ 0.3 × pipe spacing

Table 2: Energy benchmarking categories and parameters

Energy Systems	Sub-system	BC parameters	PD parameters
Air Conditioning	Electrical Chiller Plant	Plant efficiency: 0.58 kW_el / RT	Plant efficiency: 0.58 kW_el / RT
Air Distribution	Sensible Cooling	AHU Fan efficiency: 0.45 W/CMH	AHU Fan efficiency: 0.45 W/CMH
	Fresh Air supply	AHU Fan efficiency: 0.45 W/CMH	AHU Fan efficiency: 0.45 W/CMH
Water Distribution	CCTC pumps	N/A	Pump efficiency: W/CMH

Energy Benchmarking

Architects and eco-consultants use energy benchmarking to compare the improvements with baseline number. Energy benchmarking refers to the process of (i) creating the 'baseline' data – divided

into several sub-systems and the overall annual total and (ii) comparison of respective sub-systems and overall total numbers of the proposed design against the baseline. In the case of these experiments, energy benchmarking refers to (i) collection of base-case simulated energy consumption results (BC) and classifying the data into several sub-systems as mentioned in Table 2, and (ii) comparison of respective subsystems and overall energy consumption numbers between PD and BC.

The Basic Model has considered with construction and flow rate properties of 0.15m concrete thickness of CCTC layer and mass flow rate of 1500 kg/hr. The paper has also measured the variation of the CCTC system performance under different parametric conditions. The three biggest factors that influence amount of energy transferred to the zone by the CCTC system are:

a) Temperature of the chilled water in the CCTC system,
b) Mass Flow rate of the chilled water in the CCTC system, and
c) Amount of concrete that is being cooled by the CCTC system

CCTC systems optimized has been done by varying the concrete thickness of CCTC layer from 0.1m, 0.125m, 0.175m, and 0.2m and mass flow rate from 1000 kg/h, 1250 kg/h, 1750 kg/h, and 2000 kg/h. The optimum chiller plant energy efficiency has been considered as 0.58 kW/RT for all the simulation models.

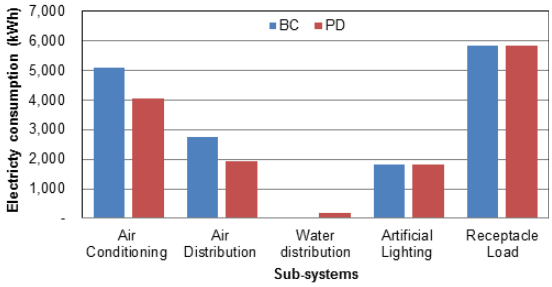


Figure 5: Comparison of subsystem energy consumption for base case and proposed design.

RESULTS AND DISCUSSIONS

Based on the models developed in TRNSYS, the reduction in energy consumption and sensible cooling requirement from air cooling system has been calculated. It can be seen from Figure 5 that the air distribution consumption is reduced by 30%, and the chiller electricity consumption reduces by 20%. Overall, there is 10.8% electricity saving for PD as compared to BC. The electricity consumption reduction for air-distribution is attributed to the reduction in air flow rate required to cool the building space (sensible cooling). The significant reduction in chiller plant consumption is attributed to the reduction in sensible cooling required by the CCTC system in PD as compared to the air cooled system in BC. The reduction in sensible cooling requirement from air cooling system is shown in Figure 6. It was observed that the cooling requirement of the air cooling system was reduced during the off-peak hours too along with reduction in cooling requirement during peak hours. Hence, it can be concluded that the thermal retention/storage property of concrete is an additional advantage to reduce cooling requiremnt.

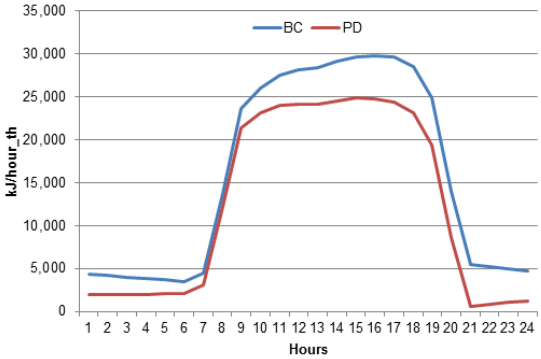


Figure 6: Comparison of sensible cooling for base case and proposed design.

The analysis of CCTC system has been optimized for various mass flow rates of CCTC water and concrete thicknesses of CCTC layer. The mass flow rate was varied from 1000 kg/h (A1), 1250 kg/h (A2), 1750 kg/h (A3), and 2000 kg/h (A4). The comparison of electricity consumption and sensible cooling demand for different mass flow rates are shown in Figure 7 and 8, respectively. As expected, the percentage savings is highest for the air-distribution system, second highest for the air-conditioning system and third highest for the total consumption. This is because the CCTC system directly affects the air-distribution system, which in turn affects the air-conditioning system and the total consumption. Hence, the effect of the CCTC system is significant on the air-distribution system.

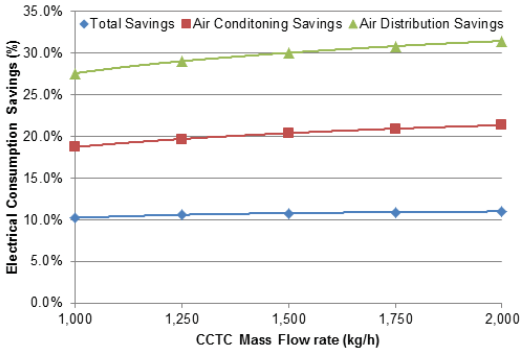


Figure 7: Consolidated comparison of electricity consumption for different mass flow rate of CCTC water.

It can be seen from Figure 8 that as the mass flow rate of the water in the system increases from 1000kg/h to 2000kg/h from A1 to A4, the amount of sensible cooling energy required from the air-cooling system is reduced. It was also noted that irrespective of the mass flow rate, it appears that the concrete retains cooling energy even after the CCTC system has been shut off. Another important observation is that the 'kick-in' time was the same for the mass flow rate range between 1000 to 2000 kg/h irrespective of the mass flow rate.

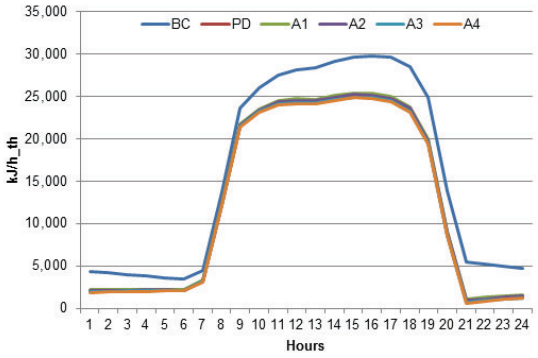


Figure 8: Consolidated comparison of sensible cooling demand for different mass flow rate of CCTC water.

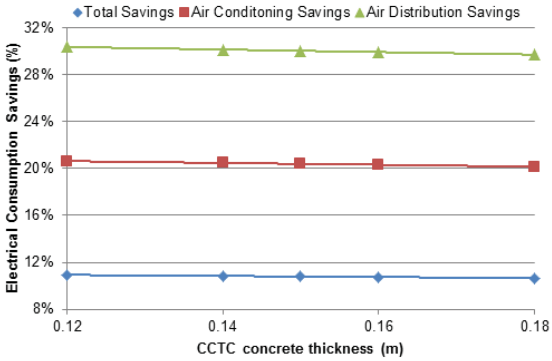


Figure 9: Consolidated comparison of electricity consumption savings for different concrete thickness of CCTC layer.

The concrete thickness of CCTC layer was varied from 0.12m (B1), 0.14m (B2), 0.16m (B3), and 0.18m (B4). The comparison of electricity consumption and sensible cooling demand for different mass flow rates are shown in Figure 9 and 10, respectively. As expected the electricity consumption (Figure 9) increased with increase in concrete thickness. It can be seen from Figure 10 that as the thickness of the concrete increases from 0.12m to 0.18m, the thermal resistance increases. Hence, with increase in the thickness of the concrete, the cooling energy supplied to the room decreases. It was also observed that during the peak hours (0700hrs-1900hrs) the amount of cooling provided by the CCTC system decreased as the amount of concrete increased.

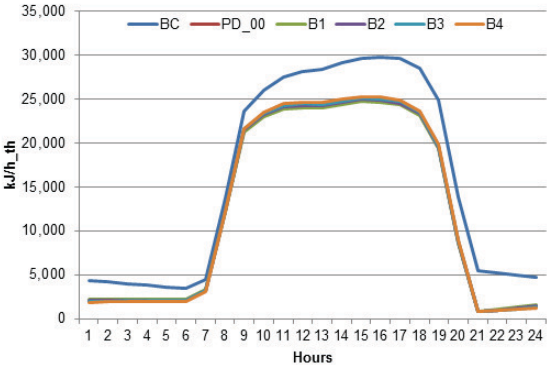


Figure 10: Consolidated comparison of sensible cooling demand for different concrete thickness of CCTC layer.

CONCLUSION

The performance of a specific type of radiant cooling system - Concrete Core Temperature Control (CCTC) has been investigated using TRNSYS software for variable mass flow rates and concrete thicknesses. The performance of the CCTC was measured in terms of indoor occupant comfort and annual energy consumption and compared to a conventional cooling and ventilation system. It was found that the as the mass flow rate of water increased the percentage saving of electricity consumption also increased. With the increase in mass flow rate, the amount of sensible cooling energy required from the air-cooling system reduced. It was also found that, the increased mass retains cooling energy and dissipates it more effectively during off-peak hours. However, it also increases the 'kick-in' time, which reduces the effectiveness of the CCTC system during the peak hours. The results from Category 'B' also clearly conclude that the electricity consumption increases with the increase in concrete mass.

ACKNOWLEDGEMENT

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HIGH-PERFORMANCE BUILDING DESIGN IN SINGAPORE: SCIENTIFIC PLANNING AND SUPPORT

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ABSTRACT

High performance buildings are characterized by high-energy efficiency, durability, indoor comfort, well-being and productivity of the occupants. This requires 'across-the-board' sustainability and efficiency practices, technologies and system integration. Scientific Planning and Support (SPS) is a process that applies i) an integrated design approach to facilitate better communication, collaboration and planning between different stakeholders, ii) scientific studies and reviews to support technology selection and system decisions in design, and iii) rigorous simulation and analysis to assess the benefits and performance implications of the decisions.

In this paper, we describe a case study of a project, a first of its kind in Singapore, which adopted the Scientific Planning and Support process to design a high performance laboratory building under local conditions. We first outline the SPS approach, and then present the execution of this approach during the planning, design and development stages. The paper concludes with the results achieved due to the SPS process, the shortcomings discovered during the execution of the project and recommended changes that for future SPS projects.

It is expected that the SPS process and the outcomes of this case study will help buildings, communities and cities achieve higher design performance goals and minimize design process waste.

INTRODUCTION

The building project, located in Singapore's first eco-business park, will house various sustainability related research institutes and companies. As such, it is a laboratory-intensive building (i.e.) a majority of spaces are expected to be occupied by labs. In line with its vision to meet the aforementioned high-energy performance standards, the building owners fittingly chose to use the SPS process to design and plan the building. The building owner appointed the Energy Research Institute @ Nanyang Technological University (ERI@N), to be the leader of the SPS effort. ERI@N chose to collaborate with the Austrian Institute of Technology (AIT) and Lawrence Berkeley National Laboratory (LBNL), because of their knowledge and expertise in similar projects across the European Union, United States of America and Asia [Parrish et al, 2012].

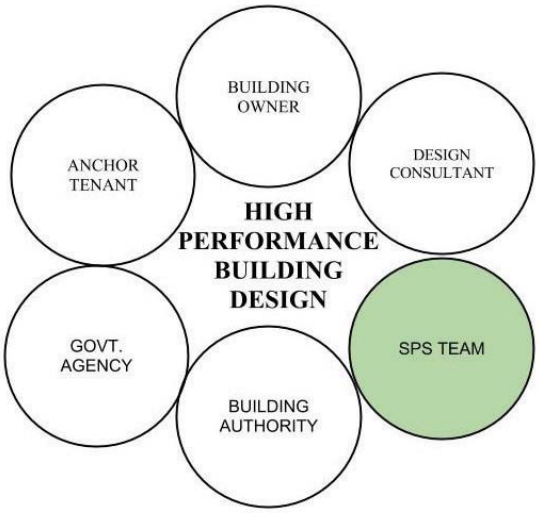


Figure 1: The Building Design Working Group

The following points are a summary of the proposed approach to achieve the greenest building concept that will surpass the Building and Construction Authority (Singapore) Green Mark (GM) v4 Platinum standard [BCA, 2010]. Further elaboration of the below mentioned points are in the following sections.

- Establish Key Performance Indicators (KPIs) for the building that targets BCA's Green Mark v4 Platinum standard and beyond

- Technology Recommendations
  Passive technology recommendations:
  a) Building Orientation and Facade Technologies
  b) Air-tightness of Building Envelope
  c) Thermal and Optical characteristics of Building Envelope
  d) Day-lighting and Shading analysis

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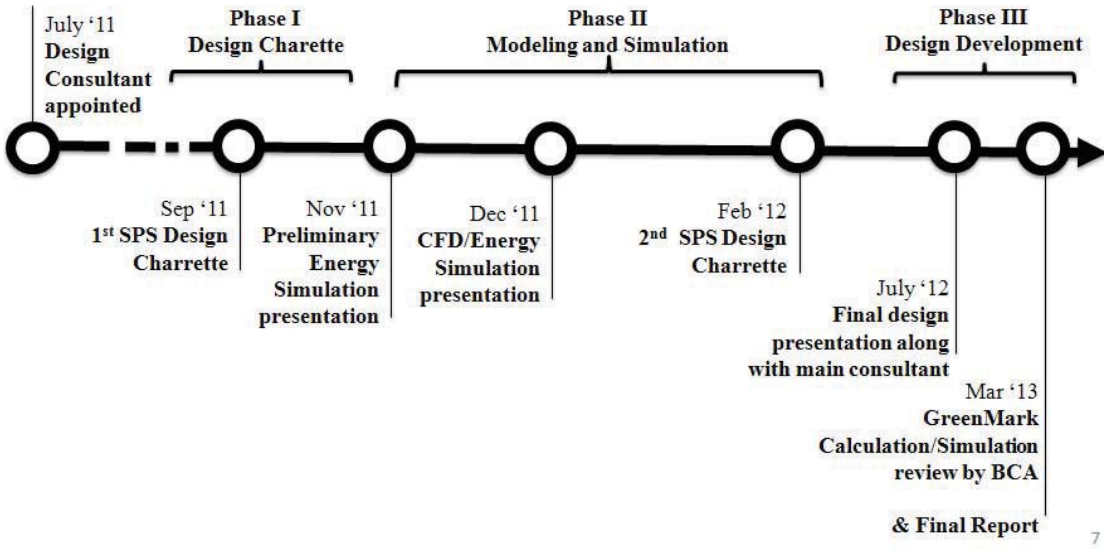


Figure 2: An Overview of the project timeline

e) Natural Ventilation, Indoor Climate and Comfort analysis

Active technology recommendations:
a) Air Conditioning & Mechanical Ventilation (ACMV) (Innovative cooling and ventilation systems)
b) Building information management and Intelligent building control application
c) Renewable Energy (Building integrated renewable sources of energy)

- Building Modelling
  a) Data Screening and Collection (building design/geometry, weather data, construction components and materials, internal loads and operational schedules)
  b) ACMV system modelling (Cooling, de-humidification, ventilation, control and energy management, detailed definition of component parameters, direct linking of building, ACMV and control model)

- Building Simulation
  a) Airflow simulation for natural ventilation using Computational Fluid Dynamic (CFD) by using ANSYS FLUENT software
  b) Energy simulation for predicting energy consumption the building by using TRNSYS software
  c) Day lighting and shading simulation by using COMFEN and eQUEST software
  d) Life cycle analysis for the applied technologies/systems

- Design Development.
  Post-modelling and simulations, a concept will be designed, iterated and implemented together with the design consultant (architects, ACMV engineers, planners, structural engineers and facility managements).

- Design Charrette and Workshops
  At the beginning of the project, an integrated Design Charrette was organized (as mentioned in Figure 1). The SPS team was joined by local experts, the design consultant, building owner, the anchor tenant, BCA and Government agencies (jointly referred to as the The Building Design Working Group as shown in Figure 1) to understand the KPIs of the building and jointly brainstorm for design and concepts that would help the building reach its targets. The Design Charrette and the subsequent workshops were planned to ensure that the building have an integrated design with input from diverse group of experts.

IDENTIFICATION OF KEY PROBLEMS

The SPS process looked keenly at the issues, which prevent most buildings from reaching the 'high-performance' status in Singapore. In addition, since this particular building is a multi-tenanted lab building, the issues targeted included problems faced while designing multi-tenanted lab buildings.

The problems (Table 1) were identified as hurdles that could prevent the building from reaching the GM Platinum standard. During the Integrated Design Charrette, the corresponding solutions were proposed and were later implemented during the project.

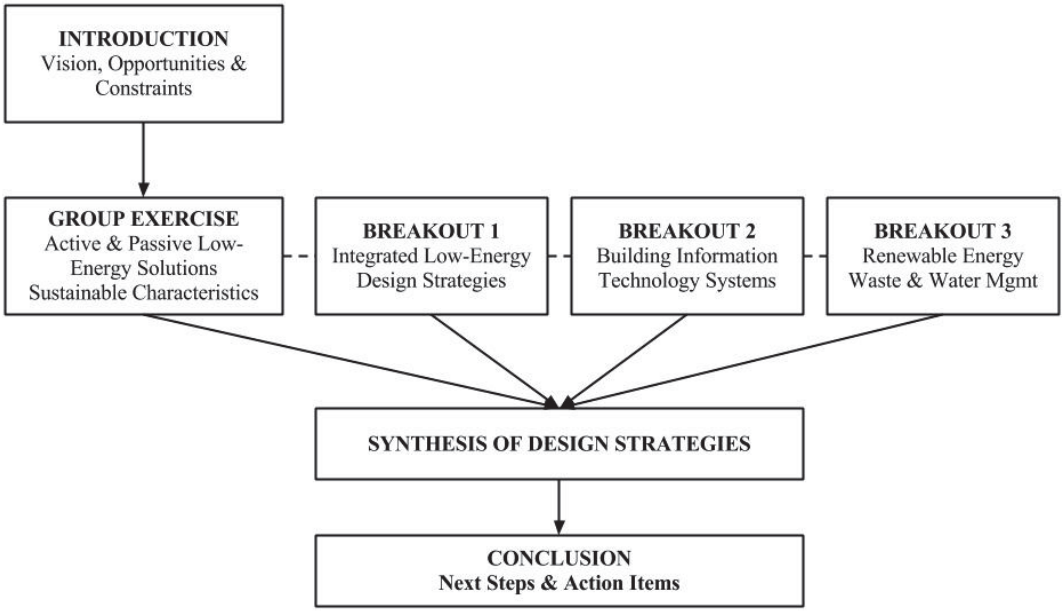


Figure 3 An Overview of the Integrated Design Charrette

Table 1
Key Problems faced while designing high performance multi-tenanted lab buildings in Singapore

	Problem	Executed Solution
1	Absence of local lab guidelines and benchmarked data	Used Labs 21 [LBNL, 2010] guidelines for internal load assumptions and ACMV equipment sizing for energy modelling and simulation
2	Lack of an integrated design effort	Organized an Integrated Design Charrette and involved key stakeholders early in the design stage
3	Lack of feasibility studies of 'Green Technologies'	Engaged relevant experts to measure the energy saving impact of technologies. Worked with product suppliers to understand the feasibility and cost-effectiveness of recommendations
4	Inefficient design/operation by tenants	Engaged anchor tenants early in the design stage. Recommended technologies that were customized to space and usage of tenants. Developed a mandatory 'Green Lease' for all tenants

INTEGRATED DESIGN CHARRETTE

In order to establish an integrated design effort, the SPS team hosted a two-day Integrated Design Charrette for the building project on 21st and 22nd Sept 2011.

The main goal of this Charrette was to identify feasible, cost-effective and sustainable measures that could be implemented. The Charrette also provided effective means to engage a wide diversity of participants in an intensive and focused brainstorming session to achieve the KPIs. 60 individuals from various backgrounds and fields: clients, university faculty and staff members, architects, engineers, government officers, green building consultants and experts, builders, and public & private company representatives participated. The two-day Charrette involved one 'Group Brainstorm' session, three 'Breakout Brainstorm' sessions, and finally the session for the synthesis of design strategies. Figure 3 represents an overview of the Charrette.

The Charrette participants shared their thoughts and creative ideas, questioned original project assumptions, and ultimately came up with innovative solutions and strategies for a high performance building. A set of action items and steps involving integrated low-energy design strategies, building information technology systems, renewable energy, and water and waste management strategies for the building were generated. A result of this exercise was

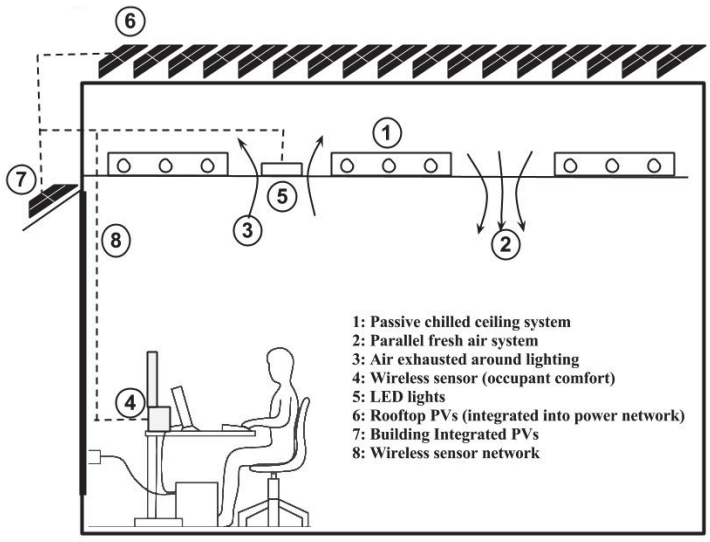


Figure 4 Initial mock-up of an office space

the creation of a 'design mock-up' of a workstation shown in Figure 4.

The SPS team, together with the design consultants, incorporated the reviewed strategies and technologies into a concept design for the building while meeting the KPIs as well as Green Mark Platinum Standard.

TECHNOLOGY RECOMMENDATIONS

The discussion during the Charrette led to several design ideas and technology solutions that aimed to increase the energy efficiency of the building. The SPS team then looked closely at the synthesis of the design strategies to understand the feasibility of the proposed strategies.

After closely studying the feasibility, energy savings benefits and cost of these strategies, a final design strategy (that reached the building KPIs and requirements for BCA GM Platinum standard), comprising of the technologies listed in Table 2, was proposed and accepted by the building owner and design consultant. It should be highlighted that the final design strategy was reached after several rounds of discussion among the Building Design Working Group (Figure 1).

Table 2 List of technologies recommended and location of implementation

	Technology Recommended	**Location**
	ACMV	
1	Best Efficiency Chiller Plant	NA
2	Optimized operation of Phase Change Material for Thermal Storage	Chiller Plant
3	Solar thermal Liquid Desiccant system [Brychta et al, 2012]	Fitted Labs & Offices
4	Demand Control Ventilation	Fitted Labs
5	Indoor Air Quality Dashboard	Fitted Labs
6	Low Energy Fume hoods	Fitted Labs
7	Stratified Cooling	High ceiling space
	Lighting	
8	Dimmable ballasts (Daylighting)	All spaces
9	LED lighting	Fitted Labs & Offices
10	Smart Parking Luminaires	Car park
	Passive Design & Renewables	
11	Low heat-transfer windows	Envelope
12	Green Walls	Envelope
13	Solar PVs & Thermal system	Roof

Apart from the technologies listed in Table 2 there were several other solutions considered, but ultimately rejected for various reasons. These technologies are listed in Table 3.

Table 3 List of technologies considered

	Technology Considered	**Location**
	ACMV	
1	Decoupling latent and sensible loads using a Dedicated Outdoor Air System	All spaces
2	Radiant Cooling	Chiller Plant
	Lighting	
3	Solar Light Tubes	Common Spaces
	Control Systems	
4	DC powered wireless sensor network	Fitted Labs & Offices
5	Neuro Predicted Mean Vote for ACMV	Fitted Labs & Offices
	Passive Design & Renewables	

6	Automated shading	Envelope
7	Reflective Coating	Roof

BUILDING MODELLING AND SIMULATION

The building modelling and simulation exercise was a very important task of the project because the design strategy that was developed needed to be evaluated. Using the modelling and simulation results, the energy saving potential of various technologies was measured and finally, the building's overall energy consumption was predicted. This section briefly describes some important results of the modelling and simulation exercise.

CFD Modelling and Simulation

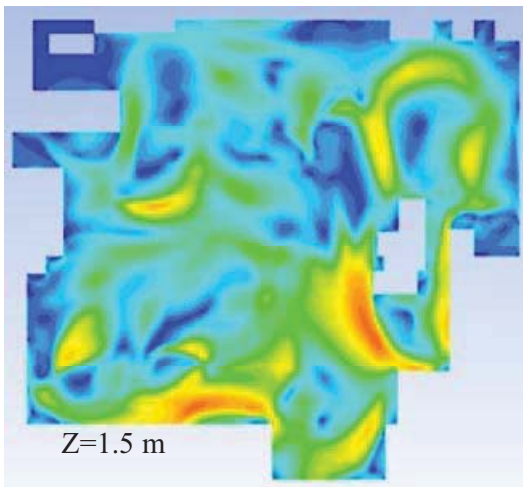


Figure 5 CFD Simulation results of the air-flow velocities in the car park of the building

The CFD Modelling and Simulation exercise was done using ANSYS FLUENT to assess the outdoor airflow in naturally and mechanically ventilated common areas, namely corridors, staircases and the car park. Figure 5 is a result of the simulation, which shows the airflow velocities in the car park of the building. It was observed that there were some areas (seen in red) which had very poor airflow velocities.

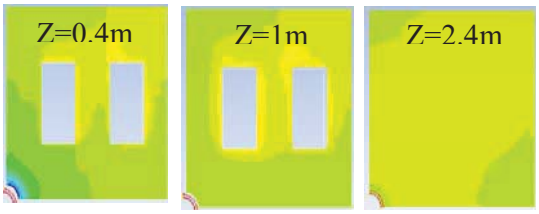


Figure 6 CFD Simulation result of temperature of a room at various heights using Stratified Cooling

In addition, indoor simulations to measure airflow and thermal comfort of innovative cooling solutions were done. Figure 6 is a result of the simulation, which shows the temperature profile of a room, at different heights, which was cooled using stratified cooling. It was observed that the temperature profile was within the required range for human comfort.

Based on the results derived from these simulations, the following changes were recommended:

- Slight architectural adjustments to relocate common areas that were naturally ventilated
- Adjustments to the jet-fan design in the car park
- The ideal indoor thermal comfort was achieved for stratified cooling technology and hence was recommended for high ceiling spaces

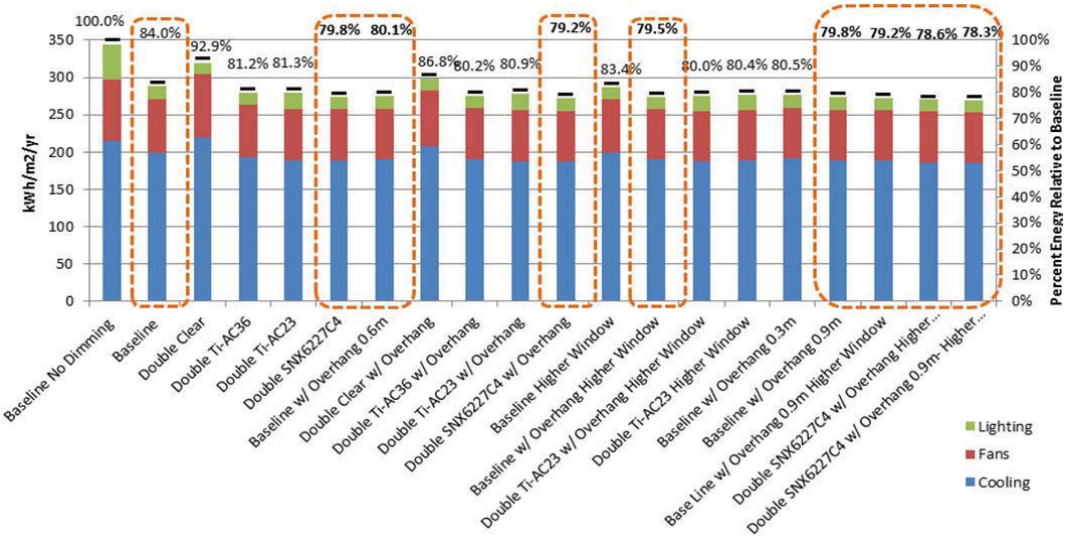


Figure 7 Parametric Analysis of a North façade window

Daylight Modelling and Simulation

Several studies were done to assess the daylighting potential for spaces in the building. Daylighting is a dynamic and interdependent feature of a building where it is critical to optimize the lighting benefits without increasing heat gain through the exterior fenestration.

The team first performed a parametric analysis for glazing systems using COMFEN and WINDOW (fenestration evaluation tools developed by LBNL). The results from the COMFEN analysis helped refine the inputs for the whole building energy simulation along with other design parameters and feedback form the system engineers. Figure 7 is one such study, which illustrates the results of an analysis for different combinations of glazing and overhang options for the north facing façade.

Apart from parametric studies, a whole building daylighting simulation was done to observe the interactions between the proposed ACMV system and the reduced lighting load, varying glazing properties and diversified glazing schedules. The daylighting analysis was performed using eQUEST, where the lighting energy savings from the eQUEST model were used to modify the lighting schedules for each zone in the energy simulation model.

Based on the results derived from these simulations:

- Two daylighting system scenarios were proposed. A conservative estimate with ON/OFF lighting control to meet 750 lux (unit of illuminance) at the work plane and more aggressive estimate using continuous dimming ballasts to meet a 500 lux at the work plane.

- According to amount of daylight available for individual spaces, daylight zone depth for each space was calculated and proposed for design.

Energy Modelling and Simulation

An integrated building energy model using TRNSYS was done after collecting all the input data and system parameters. Results from the CFD and daylight modelling and simulations were also incorporated in the energy model. After creating the geometry, the design strategy was replicated in the TRNSYS platform to mimic the actual building operation. The total building energy consumption and energy consumption of individual systems was derived from the results of the simulation.

The total building energy savings was found to be 31.2%. This is higher than the 30% savings requirement to achieve Green Mark v4 Platinum standard. A brief summary of these results are listed in Table 4.

Table 4 Energy savings of individual energy systems in the building

	System	% Savings*
1	Chiller Plant	30.5
2	Air Distribution	52
3	Lighting	47
4	Lifts	10
5	Pumps	0
6	Plug Load	0
	Total	**31.2**

**Improvement from the building compliance/baseline standard*

Another outcome of the energy modelling and simulation exercise was the development of a mandatory 'Green Lease'. After initial simulation runs, it was found that since tenants controlled the vast majority of spaces in the building, energy efficiency measures for tenant-controlled infrastructure and tenant-occupied spaces were necessary to achieve high-energy savings. Three key measures were identified and a 'Green Lease' document was produced. Table 5 is a summary of the Green Lease items.

Table 5 Mandatory Green Lease to for all tenants

	Item	% Improve*
1	AHU / FCU Fan Power Rating	20
2	Electrical Lighting Power Density	30
3	Daylighting (Daylight zone = Distance between floor to the top of the window)	

**Improvement from the building compliance/baseline standard*

LEARNING POINTS

The SPS process was first of its kind in Singapore. Although the SPS team managed to achieve the building KPIs, as with any first-time effort, there were aspects of the SPS process that have scope for improvement. It is hoped that future projects that implement the SPS process for integrated building design will incorporate these improvements. Below are two of the most important aspects that could be improved upon.

Improved Timeline:
The SPS team should be appointed before the design consultants. If the SPS team is appointed even before the building's performance goals are established, the SPS team can work together with the building owner

and design consultant candidates to establish specific goals by understanding the building requirement, studying performances of energy efficient buildings around the world and factoring in local costs, user behaviour and other constraints. After the design consultant is appointed, the Building Design Working Group can work together to ensure that the vision for the building is carried out as per the set objectives.

Robust Energy Saving Comparison

During the project, several technologies were studied before finalizing an integrated design. The life cycle cost of these technologies (capital, operational and maintenance) and respective energy savings were studied before a decision was made. Although this is a thorough process, the best way to select a certain system over another is to understand the different energy saving combinations and compare their costs and energy saving potential. Such a method should be employed to aid during decision-making processes for future SPS projects.

For example, there are several combinations of external shading-lighting-cooling strategies that could be implemented. A comparative study of these options would make it easier to decide on the shading system (automated, geometry), lighting (daylight perimeter, type of lighting) and cooling (technology, set points, schedules) that is best suited.

CONCLUSION

The project concluded with all of the building KPIs achieved. Despite the unconventional design process and strict project timeline, the SPS team received a lot of support, cooperation and motivation from the rest of the Building Design Working Group, especially from the building owner and the design consultant. This pilot SPS project proved the benefits of the SPS process and demonstrated that such a process can be executed in Singapore.

Members of the SPS team saw great benefits as a result of this project. Those involved with the modelling and simulation exercises gained very valuable industry experience. Another benefit of this project was the successful collaboration between ERI@N, AIT and LBNL resulted in capability building through greater understanding of energy-efficient technologies and simulation methods.

NOMENCLATURE

ACMV	Air Conditioning & Mechanical Ventilation
AHU	Air Handling Unit
AIT	Austrian Institute of Technology
BCA	Building and Construction Authority
CFD	Computational Fluid Dynamics
COMFEN	Commercial Fenestration Tool
eQUEST	Quick Energy Simulation Tool
ERI@N	Energy research Institute @ NTU
FCU	Fan Coil Unit
GM	Green Mark Version 4
KPI	Key Performance Indicator
LBNL	Lawrence Berkley National Laboratory
LED	Light Emitting Diode
NTU	Nanyang Technological University
PV	Photo Voltaic
SPS	Scientific Planning and Support

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AN ANALYSIS OF THE PRE-CERTIFIED ACQUIRED SCORE RESULTS IN 2012 FOR MULTI-RESIDENTIAL BUILDINGS BY G-SEED CRITERIA 2011

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ABSTRACT

Korea Green Building Certification Criteria has officially named as G-SEED (Green Standard for Energy and Environmental Design) recently. G-SEED has been in the force since 2002 in Korea. 74 percents of total cases are certified with criteria 2011 in 2012. This study proposes to research the current condition of G-SEED for multi-residential buildings as investigating the acquired score data. This paper investigates acquired score results in 2012 of pre-certified multi-residential buildings by criteria 2011 and analyzes the results of pre-certified multi-residential buildings as case studies and average acquired scores from classfied levels, categories, and items of invatigation cases. This research also seeks to be used as a reference guide for future augmentations of G-SEED.

Keywords: G-SEED, multi-residential buildings, Acquired Score Results

INTRODUCTION

1. Research Purpose

Korea Green Building Certification Criteria has officially named as G-SEED (Green Standard for Energy and Environmental Design) recently. G-SEED was first enrolled in 2002 with multi-residential buildings as targets, and the classification criteria was revised. As a result of a dominantly high record number of G-SEED for multi-residential buildings (a popular building type of residence in Korea) and a continued rise in environmentally friendly multi-residential buildings, the certification criteria for multi-residential buildings came about in 4 different stages. A policy to increase residents' level of satisfaction via a sustained development and improvement to the certification criteria.

This research analyzed the results of G-SEED with pre-certified multi-residential buildings as case studies. This research also analyzed the average scores from classified levels, categories, and items via investigation from the acquired scores of G-SEED for multi-residential buildings in 2012.

2. Descriptions

2012 G-SEED for multi-residential building certification assessment was done by a total of three certification criterion 2010 (effective as of 2010.05.17), 2011 (effective as of 2011.12.30), and 2012 (effective as of 2012.07.01). The certification criteria that are under assessment depend on the application date, and the certificate record report are done on the date of certification.

All certificate criteria of 2010, 2011, and 2012 assessment comprise of 4 classified levels of Green 1st Class, Green 2nd Class, Green 3 rd Class, Green 4 th Class. The standards on minimum acquired scores are the same as above criteria. The standards have to fulfil above 74 points for Green 1st Class, 66 for Green 2 nd Class, 58 for Green 3 rd Class, and 50 for Green 4 th Class.

CURRENT STATUS OF G-SEED FOR MULTI-RESIDENTIAL IN 2012

Table 1 shows the cases of multi-residential assessment cases from the past 3 years between 2010 and 2012. Compared to 2010, the number of cases sharply dropped down in 2011 but it came back up in 2012. The total number of pre-certified multi-residential buildings in 2012 was at 136.

Table1. The number of multi-residential building certification assessments done over the past 3 years

	2010	2011	2012
Final Certification	102	71	46
Pre-Certification	98	57	136
Total	200	128	180

(Source: Korean Ministry of Land, Infrastructure and Transport website)

The pre-certified multi-residential buildings were all assessed with different certification criteria as certification criteria were revised three times in 3 years. Table 2 data, provided by Ministry of Land, Infrastructure, and Transport, shows the number of multi-residential cases between criteria 2010 and

Table 2. The total number of certified cases on multi-residential buildings by certification bodies

	A	B	C	D	E	F	Total
Criteria 2010	1	11		19			31
Criteria 2011	18	20	3	60			101
Criteria 2012					2	2	4
Total	19	31	3	79	2	2	136

(A to Z: Designated Certification Bodies)

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criteria 2011 from the each designated certification bodies. The total number of pre-certified building is 101 among 136 in 2012.

CASE ANALYSIS

1. Distribution of Multi-Residential Building Cases by Criteria 2011

All 101 of pre-certified assessment results in criteria 2011 were researched in order to analyze the assessment process of pre-certified process for multi-residential buildings in 2012. The most recorded classfied levels is Green 2nd Class. Also, the one-third of the 101 buildings achieved Green 4th Class.

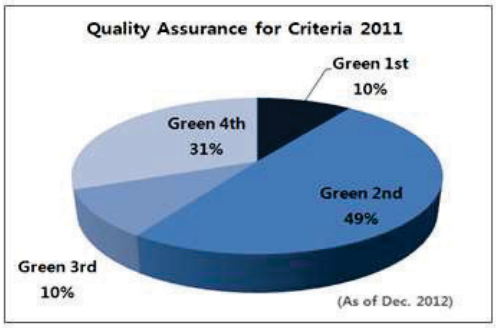


Figure 1. Distribution of pre-certified cases by classified levels with criteria 2011 Assessment

2. Comparision of Assessement Results per Classified Levels by category

Table 3. Average acquired scores per classified level of criteria 2011 cases by category

Category \ Level		Average Score				⊿Score (Max-Min)
		Green 1st	Green 2nd	Green 3rd	Green 4th	
Land Use	10	6.2	6.5	5.3	4.9	**1.6**
Transport	5	4.1	4.1	3.8	3.5	0.6
Energy	20	17.8	16.2	13.1	9.1	**8.7**
Materials	15	11.58	9.59	7.99	7.38	4.2
Water	10	6.3	5.8	4.3	3.6	**2.7**
Pollution Prevention	5	2.3	2.6	2.5	1.9	0.7
Mainten.	5	4.9	4.9	5.0	4.8	0.2
Ecology	10	5.8	4.7	3.7	3.9	**2.1**
Indoor Envrn.	20	13.4	13.1	13.6	12.6	1.0
Total	**100**	**76.3**	**70.9**	**61.8**	**54.1**	

Table 3 shows average acquired scores per each classified level and category of the 101 pre-certification assessment results. In condition of the average acquired scores, Green 1st Class is the highest and Green 4th Class is the lowest in most cases. Green 2nd Class acquired the highest average scores from the Land Use categofy while Green 3rd Class acquired the highest average scores from the Maintenance and Indoor Environment.

difference (⊿Score) Regarding to difference (⊿Score) of the average acquired scores between Green 1st Class and Green 4th Class, Energy, Materials and Resources, and Water category are comparatively high. It can be considered that they contribute on the classified level. On the other hand, Transport, Pollution Prevention, Maintenance, and Indoor Environment do not. ; thus once can assume that Energy, Materials and Resources, and Water category affect to classified level.

As difference (⊿Score) between the highest and the lowest average acquired scores for Energy, Materials and Resources, and Water are high, it can be deducted that the above categories have a big influence on the certification levels. On the other hand, Transport, Pollution Prevention, Maintenance, and Indoor Environment do not show a big difference (⊿Score) between the highest and the lowest average acquired scores; thus once can assume that certain amount of points are difficult to gain regardless of certification level or that these are categories that can be consistently scored.

With regards to Energy category, difference (⊿Score) between the highest and the lowest average acquired scores is big while the acquired score ratio to total is 89 percent in Green 1st Class. and 46 percent in Green 4th Class. On the other hand, difference (ΔScore) between the highest and the lowest average acquired scores is comparatively big in the Water category while the acquired score ratio to total of both Green 1st Class and Green 4th Class is not high; 52 percent in Green 1st Class and 38 percent in Green 4th Class. There is a concern that the Energy category allows to earn higher score with efforts while Water category has limits to earn more points in practice.

Regarding to Transportation, Pollution Prevention, Maintenance, and Indoor Envirionment category, none of Green 1st Class acquired the highest average scores and difference (⊿Score) between the highest and the lowest average acquired scores is not big. There are almost no difference of the average acquired scores and difference between the highest and the lowest average acquired scores is under 1 point.

3. Comparision of Assessement Results per Classified Levels by item

The highest average acquired scores are recorded on Green 2nd Class in Land Use, Pollution, Maintenace, and Indoor Environment category according to the Table 3. Land Use categoy needed to investigated on each item's results because the difference (⊿Score) among all levels is hardly existing. With regards to Land Use, the difference (⊿Score) between the highest and the lowest average acquired scores is big but since the average acquired score of Green 2nd Class is higher on Land Use category than that of Green 1st Class (Table 3), and the average acquired scores by items in Land Use category was analyzed (Table 4).

Table 4. Average Acquired Scores of Levels per items under Land Use with Criteria 2011

Land Use (points)		Average Acquired Scores			
		①	②	③	④
1.1.1 Ecological Value of Existing Site	2	0.6	1.2	0.8	0.4
1.2.1 Asibility of the measure prevent interference of skylight right	2	0.4	0.3	0	0.2
1.3.1 Community Center or Facility	3	3.0	2.8	2.4	2.6
1.3.2 Pedestrian Street on the Site	3	3.0	2.8	2.7	2.5
1.3.3 On-site and Off-site pedestrian street Connection	2	0.5	0.6	0.4	0.3

(① Green 1st Class, ②Green 2nd Class, ③Green 3rd Class, ④Green 4th Class)

With regards to Pollution Prevention, difference (⊿Score) between the highest and the lowest average acquired scores is not big but since the average acquired score of Green 3rd Class is the highest in this category than those of Green 1st Class and Green 2nd Class (Table 3), and the average acquired scores by items in Pollution Prevention category was analyzed (Table 5).

With regards to the 6.1.1 Reducing CO_2 emission, the highest average acquired scores is on Green 3rd Class, the average acquired scores on Green 2nd Class is higher than that of Green 1st Class, and the average acquired scores on Green 4th Class is the lowest. It is concerned that the technology of reducing CO_2 emission in practice is not distinguishable despite of extra efforts or costs.

Table 5. Average Acquired Scores of Levels per items under Pollution Prevention with Criteria 2011

Pollution Prevention (points)		Average Acquired Scores			
		①	②	③	④
6.1.1 Reducing CO_2 emission	3	1.3	1.58	2	1.13
6.1.2 Prevention of ozone destroying material	3	1.5	1.54	1	1.16

(① Green 1st Class, ②Green 2nd Class, ③Green 3rd Class, ④Green 4th Class)

CONCLUSION

This research analyzed the G-SEED assessment results with criteria 2011 for pre-certified multi-residential buildings in 2012. Regarding to the G-SEED for multi-residential buildings in 2012, three different criteria versions (criteria 2010, 2011, and 2012) requested for used. Out of 136 multi-residential buildings, 101 cases among all were certified with criteria 2011. The research target were to investigate 101 cases with criteria 2011 and analyzed the average acquired scores by classified levels, categories, and items for the sake of continued development and improvement. Among 101 cases, 59 percent of pre-certified assessment results in criteria 2011 were on Green 1st Class and Green 2nd Class.

There is a concern that the average acquired scores from Energy, Materials and Resource, and Water category have a big influence on the certified levels. There are items that are not distinguishable among levels on Pollution Prevention, Maintenance, and Indoor Environment category. Concerning Land Use and Pollution Prevention category, it appears that the standards on these items barely affect on distinguishable classified levels. Items of them need to be developed to be more adoptable in practice if owner wants to put extra efforts or costs. This research will be used as a reference guide for future augmentations of G-SEED.

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AN INTEGRATED ICT BASED FRAMEWORK FOR SMART SUSTAINABLE CITIES IN A TROPICAL ENVIRONMENT

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ABSTRACT

There is major demographic shift occurring globally, for the first time in human history more people live in cities than in a rural environment. It is estimated that today approximately 50 % of the world's population lives in an urban environment and this is estimated to grow to up to 70 % by 2050. Tropical areas are an increasingly critical region on the world map, home to more than 40 % of the world's population and generating about 20 % of global economic output.

Traditional approaches of reducing carbon foot-print of cities include (i) alternative sources of energy, such as solar, (ii) environment friendly living such as recycling, and development of energy efficient equipment and buildings. An integrated approach of managing energy consumption and related sustainable activities within a city with the help of Information & Communications Technologies (ICT) can enable capture of energy and sustainability data at the finest granularity level. This data can be used to develop analytics and to manage the overall sustainable behavior of city.

This paper describes an integrated framework for managing various aspects of cities that would balance / optimize the various complex and conflicting priorities such as safety, security, efficient city services, education, and health care with the objective of reducing overall energy consumption. Information is power. Such information would also enable people and managers of the city to benchmark with other equivalent areas, adopt best practices and develop best of breed sustainable policies.

This paper will examine the role of ICT in a smart eco-city and propose a robust and methodologically sound approach for a sustainable energy efficient eco-city which will tie together the end-user (citizen) experience across the multiple dimensions ranging from healthcare, living, workplace, shopping, education, transport and government above with the internet and its technology backbone infrastructure.

INTRODUCTION

Across the world, cities account between 60-80 % of the global energy consumption and greenhouse gas (GHG) emissions.

The number of "mega-cities" defined in terms of population in the excess of 10 million, has grown from 3 in 1975 to over 25 over the next 10-15 years (Toppeta, 2011). There are currently 102 smart city projects running worldwide including Songdo ($42B) in Korea, Lavasa ($100M), Kochi, DMIC Corridor in India, 18+ cities in China including Ningbo ($6B), Wuxi, Cafeidian, Beijing, Shanghai, Shenyang, Masdar ($22B) in Abu Dhabi. Tropical Asia features predominantly in this list of "mega cities".

There are many physical infrastructural aspects of a typical city among them the following are pivotal :

a. Buildings
b. Utilities & Energy
c. Mobility (Transport)
d. Water Management

ICT forms one the great equalizers to help balance / optimize against the various complex and conflicting priorities such as safety and security, efficient city services, education, and health care. ICT is what makes the city "smart", enabling connectivity, aggregate and analyze real-time and historical data to take appropriate action, facilitate social and other interactions, helping spur economic, social, and environmental sustainability, and therefore enhance the quality of life for citizens.

This paper examines the role of ICT in a smart eco-city and proposes a robust and methodologically sound approach in the form of an integrated framework which ties both physical infrastructure and information technologies (ICT) for a sustainable energy efficient smart eco-city.

PHYSICAL INFRASTRUCTURE ELEMENTS

In reviewing the literature, we found that there has been considerable research related to "smart and sustainable" for each of the four infrastructure pivots mentioned earlier – Buildings, Mobility, Utilities/Energy and Water. The impact of this research has been considerable in advancing the state of art in their individual "siloed" domains but in aggregate has not addressed the relationships and influence of one vertical domain on another for example the relationship between utilities & energy and water or mobility (transport).

Buildings: Buildings form undoubtedly the largest footprint in high-dense or mega cities. Stifter and Kathan (2011) describe buildings in such future smart cities as key infrastructural component in leveraging the fact that high-dense cities lack space and

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buildings in such places predominantly occupy more than two-thirds of gross area. The building and city infrastructure represents the state of the art in civil engineering. In recent times, efforts in minimizing energy consumption in buildings became fore runner than simple architecture.

Alarmingly, research evidences (Price, Michaelis et al. 1998, de Ia Rue du Can and Price 2008) are available today that buildings – places of work, living, navigation & leisure in urban environment, have been one of the greatest contributor to greenhouse gas emissions (GHG). In addition, several climate scientists and researchers in (Rizwan, Dennis et al. 2008, Yang, Lau et al. 2010, Loughner, Allen et al. 2012) have found that urban geometry constituting of mass of buildings largely contribute to the imbalance in urban microclimate through a phenomenon widely noticed as Urban Heat Island (UHI). In addition, rapid efforts are underway through constitutionalizing building codes and standards such as U.S. LEED, Green Mark Scheme, BREAM among many, which are making striving efforts through efficient use of building components, systems and practices to keep building's ecological footprint under control.

Many proposed frameworks & operational models through case studies (Agarwal, Weng et al. 2011, Rezaie, Esmailzadeh et al. 2011, Sioshansi 2011, Milan, Bojesen et al. 2012) serve promising evidence to potentially meeting the rising energy demands through distributed and decentralized energy hubs in such cities. With the technological competence available around the corner, the concept of building integrated micro grid (BIMG) evolved. Combining already available power generation technologies, predominantly photovoltaics (PV) in the building context to conceptualize building integrated photovoltaics (BIPV). Sioshansi (2011) observed that BIMG could offset 90% of building's tertiary energy loads, which operate fundamentally on direct current (DC) power conveniently by having a DC micro grid for the building scale. This made realizing net-zero energy buildings (nZEB) practical.

Collection of these features makes conventional buildings 'smarter'. By this we mean, various active building systems like HVAC, lighting, mobility, plumbing etc. We can now interact with passive systems like envelope (facade, shades) through ICT to optimize operational energy efficiency without compromising occupancy comfort. Building Management Systems (BMS) help achieve this through central co-operative actions among these disparate systems. Conventionally, BMS is achieved through wired means such as Supervisory Control and Data Acquisition (SCADA) (Figueiredo and Sá da Costa 2012) while in recent times several intelligent building management systems combined pervasive wireless technology non-invasively (Oksa, Soini et al. 2008, Wong and Li 2009).

Utilities & Energy: Constantly making new peaks in terms of demand, energy is critically required for plethora of tasks & activities ranging across city's day-to-day events. The three most important aspect of Energy are (1) exploration for new sources of energy (2) efficient management of existing non-renewable energy sources (3) effectively combining the two above. While first is beyond the scope of this study but the other two aspects can be addressed with the help of smart grids, smart energy management systems and so on in this work.

A major constraint of energy is its efficient storage. To overcome this constraint, we need a system of production and consumption of energy in real time. Smart grids are the examples of such innovative architecture. Smart grids (Massoud Amin and Wollenberg 2005) are the combination of conventional & modern non-fossil based energy systems glued seamlessly by advanced ICT technologies. This step forward leverages on totally desperate energy systems - few centralized and many distributed sources talking to each other in real-time. While there is no single definition of the Smart Grid, the expectation is that the current grid network with advanced sensors and actuators and a highly secure networking infrastructure to improve grid efficiency, performance, and reliability..

Agarwal et al (2007) presented technological components & their use methods to demonstrate 'micro grid' framework at campus or city scale which conceptualizes a framework addressing the integrity of diverse forms of distributed energy sources - fossil & non-fossil based, local co-generation and storage facilities.

Zero Net Energy (ZNE) concepts can be extended to the scale of campuses, complex, town or even a city. As a word of caution (Zhivov, Liesen et al. 2011) study reminds that for ZNE to be applied at wide scale, seamless blend of energy conservation through efficient systems & practises through building management systems at every individual building level, utility management and control, and power distribution systems all should have capability to integrate to on-site renewable in real-time.

Platt, Berry et al (2012) highlight the challenge in realizing such a smart grid, which is limiting enthusiasm for its large-scale adoption. Hence, as an alternate Platt proposes *microgrids*, which are a collection of geographically proximate, electrically connected loads and generators. It's tree-like structure strikes advantage over the conventional radial structure of the grid, which forms the core

challenge in modernizing the control and operation of contemporary power system.

Orecchini and Santiangeli (2011) assert that sustainable energy future foresees no predominance of one source over the other but a proper energy mix, based on locally available resources and needs. This necessitates need for intelligent management of a complete set of energy sources and vectors such as electricity, heat, hydrogen, bio- or non bio-fuels, which goes beyond smart grid to an Intelligent Energy Networks (IEN).

Inspired by the way revolutionary 'Internet' technology has been embraced by the world, Katz et al (2011) brings out the principles in formulating a new information-centric energy network for 21st century. This approach can help achieve improved efficiency in how energy is generated, distributed, consumed and how to agilely dispatch it to where it is needed by appropriately integrating intermittent energy sources and loads to match available energy.

Mobility: Mobility (transport) is one of the four significant pillars of Smart city framework. It broadly includes different ways in which dwellers of a city communicate from one place to another. It comprises mainly the public and the private transport. The residents of a smart city expects the transportations facilities to be safe, low cost, time efficient, comfortable as well as environmental friendly (Haque, Chin et al. 2013).

In the field of Mobility, researchers have developed innovative, cost efficient and environment friendly ways of transportation. The most momentous are innovations in area of electric and solar power vehicles. Though there are multiple challenges with cost and efficiency of these vehicles, indeed it is a revolutionary move in area of future transportations

To examine the different available modes of transportations based on the aforementioned expectations, there is a need to define parameters quantitatively to judge the different mobility solutions. Safety of a transport solution can be determined by number of accidents per unit time caused due to particular mode of transport system. There is always a trade-off between cost and time efficiency when transportation is concerned. However, with help of efficient Mass Rapid Transit Systems (MRT), a balance between cost and time can be maintained for the majority of the population of the Smart City. There are various dimensions to measure the environmental impact due to transportation. The amount of different poisonous gases in the atmosphere of the city per unit volume of air determines the environment impact (Haque, Chin et al. 2013). Going forward, there is a tremendous need for trans- potation modes, which are electric, powered or runs on green fuels like Liquefied Petroleum Gas (LPG).

Gunnar and Kent (2009) have discussed a smart-transportation framework where the right transportation mechanism needs to be selected best of available options, quality of life to be provided, energy consumption and pollution impact. Kim et al (2010) have proposed a scheme for optimal job ordering in electric vehicle charging station. For example, if there is a limited charging station of scarcity in available electrical energy, the smart city framework needs selection the vehicles to charge to maintain all aspects of a city. Such decisions on mobility not only influence the transportation aspects of a smart city but all other aspects of a city life.

To improve the quality of mobility, we need to integrate the mobility pillar with the ICT infrastructure layer. This will enable the smart decisions at both individual level (for example going to office by metro rail vs. private vehicles) and at the community level (expanding the road will allow more frequent bus services, which may be better than expanding another metro-rail network in the area). This layer not only connects mobility with rest of the three major pillars of smart city, it also connects to the above layers in the proposed framework. An example application would be to determine the optimal transport mechanism (mobility pillar) from location to another location if currently an event is going in the football stadium (building pillar).

Water: With water forming the most vital component (Ausubel and Herman 1988) of any urban livelihood combined with the fact that water as a resource is at its critical tipping point in many urban cities (Brown, Keath et al. 2008), it is relevant to compose water in the context of future smart city framework.

Water and wastewater treatment is an essential ingredient in the successful and sustainable operation of an urban environment. Some needs include :

- Minimize water consumption, ensure water quality, maintain and operate the system efficiently under consistent operation
- Automatically detect, analyze and respond to malfunctions and optimize asset use.
- Include various sources of water both from conventional sources, surface and ground water, from reused water from processes like desalination.

There is a clear analogy between applying "smart" technologies to water infrastructure and smart-grid technologies, which are being proposed and tested to not only make the grid run more efficiently but also use more renewable energies. Water agencies can optimize their operations with improved data

gathering and processing for example, real time on-line leakage detection mechanisms, water quality indices and better water security.

Olsson (2012) discusses that instrumentation, control and automation (ICA) is an essential ingredient for water and wastewater treatment systems. The scope of such ICA includes (1) Keeping the plant running (under operation: mostly controlled automatically) (2) satisfying effluent requirements (automatic control of dissolved oxygen, sludge age, return sludge etc) and (3) maximizing energy efficiency and optimizing plant capacity.

Some roles where ICT shall continue to play key role in a smart water grid as presented in (Olsson 2012) includes

- Modelling for control through sensor and actuators
- Data analysis and monitoring including leaks
- process control aspects in waste water treatment
- Controlling drinking water system

Nguyen, Zhang et al. (2010) have developed an intelligent model to categorize residential water end use events. The aim of this study was to disaggregate water flow data collected from high resolution smart water meters into different water end use categories such as shower, washing clothes etc.). The researchers developed a complex pattern matching algorithms, which are able to automatically categorise collected flow trace data points received from wireless data loggers into particular water end-use categories. They have conceptualized a Knowledge Management System (KMS), which is able to collect real-time water consumption data through a smart water metering system, transfer and store the data into a knowledge repository, analyze and disaggregate data into a registry of end use events.

Shihu (2011) proposes an Advanced Metering Infrastructure (AMI) to achieve the goals of water distribution network optimization. Online flow, pressure and water quality data is essential to the hydraulic and water quality model calibration that make the water system management digital and reasonable. A set of online monitor sensors including smart flow and pressure meters, water quality sensors, smart water consumption meters and leakage monitoring sensors were installed in the water distribution networks which was connected to a SCADA system.

Lima and Navas (2012) propose an automated system for remote metering and sub-metering of water and electricity (internal to the residence, installed at interest points) and then integrated into a structured knowledge tool. Such a tool will enable utilities to allow their customers to analyze monitor and control their consumption of these services in real time. Such an integrated approach provides customers and utility companies with compiled reports containing the historical use, daily and hourly forecasts, and projected savings due to changes in consumption habits and/or use of more efficient equipment.

Allen, Preis et al. (2012) present an end to end, integrated hardware and software centric, on-line, real time diagnostic and monitoring system called Water Wise, which was successfully implemented in Singapore to optimize system operations, manage leakage control more effectively, minimize disruptive repairs and maintenance. Water Wise's sensing and software platforms have helped improve the operational efficiency of the water supply system in Singapore.

ICT ACTING AS AN INTEGRATOR

ICT forms the nervous system of the most of the models proposed for future smart cities. Authors have categorized them as Internet of Things (IoT) and Internet of Services (IoS). The first represents the infrastructure and later represents the applications of ICT (Hernández-Muñoz, Vercher et al. 2011). Current ICT infrastructure in the cities cannot support the requirement of Smart cities in terms of data collection and processing.

In the last decade, the research community has perceived and acknowledged the big innovations, which took place in ICT infrastructure and its applications. It includes the major telecom platform, ubiquitous sensor networks (handheld, distributed ambient sensing & actuating nodes) and data centres (including processing and storage). We have seen emergence of 3G/4G telecom and data networks which provides enormous bandwidth. On the other hand, sensors have become smarter and more efficient and are available to accurately measure any phenomenon of a city. ICT applications comprise of the intelligent integrated applications, which runs on ICT infrastructure, which hides the underlying complex system and offers simplistic means for the end-users with rich and easy interaction. Some examples are e-commerce, telemedicine etc. In the context of smart cities, ICT provides the connectivity among the various backbone activities of any typical city. It offers end-user with intuitive means to take smart decisions. The innovations in ICT provided an opportunity for researchers in aforementioned domains to collaborate in conceptualizing and designing Smart cities framework. This leads to an integrated architectural model of Smart Cities.

EXISTING INDUSTRY CITY FRAMEWORKS

Recognizing that ICT is a major facet in Smart and Sustainable cities, a variety of leading industry

players such as IBM, LG, Living PlanIT have launched platforms for the urban landscape.

IBM (IBM 2013) (Michael Kehoe 2011) has launched a "Smarter Planet" initiative which consists of a multifaceted approach to developing more sustainable and intelligent cities and therefore the planet. From its vast experience working with many urban environments across the world, it has developed key domains that factor into cities. These include Analytics, Buildings, Cities, Communications, Computing, Education, Energy, Government, Healthcare, Retail, Safety & Security, Traffic and Transportation and Sustainability.

IBM believes that across all of these domains, there will always be capabilities or attributes in a city that fall "in between" – hence the need to aggregate and "integrate" cross-domain information. All the relevant information can be collected, analyzed and then appropriate action taken by the decision makers or city administration.

The initial focus is on critical, city-wide issues which need to be addressed via the integration and analysis of real time and historical data from the following four domains - public safety, transport/traffic management and water management. In a smart city, this central repository of information can be classified as an "Intelligent Operations Center (IOC)" which acts as a central "city dashboard". Different an analytical capabilities and rules engines for the different domains are built into the IOC.

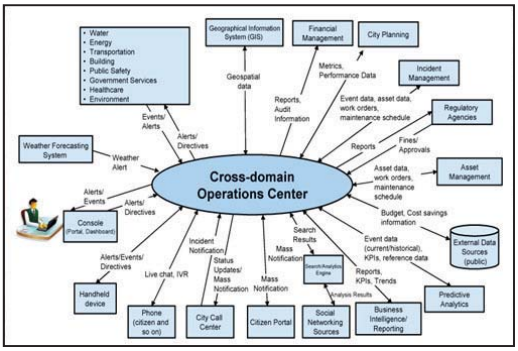


Figure 1 IBM Intelligent Operations Center

The detailed technology infrastructure beneath this IOC is reflected in an architecture which has 3 tenets: Instrumented, Interconnected and Intelligent.

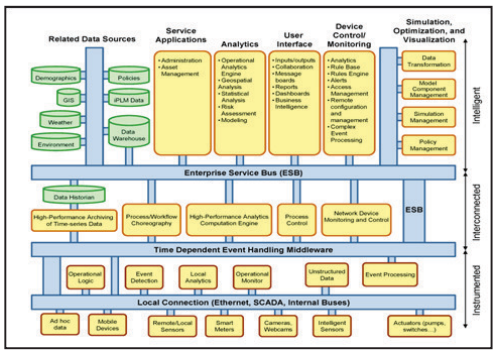


Figure 2 IBM Smarter Planet Platform

Living PlanIT (LivingPlanIT 2013) has developed an operating system for cities that looks just like a PC operating system that it calls UrbanOS or the Platform for the 'Industrialization of the Internet'. It intelligently monitors and automates traffic lights, air-conditioning, water management systems which influence the quality of life while driving down the costs of operating a city. In their view, the city is a network which behaves analogous to the nervous system in the human body (think buildings and streets) with many distributed sensors gathering data and then synthesizing actions.

UrbanOS is a programming platform and operating infrastructure which collects, aggregates, orchestrates and analyzes the data from the sensor and intelligent device environment distributed across the different sub-systems: buildings, traffic, energy, water, waste, education, and transportation. It has four major layers / components: End-Use Applications, Supervisory Layer, Controls and Sensory or Hardware.

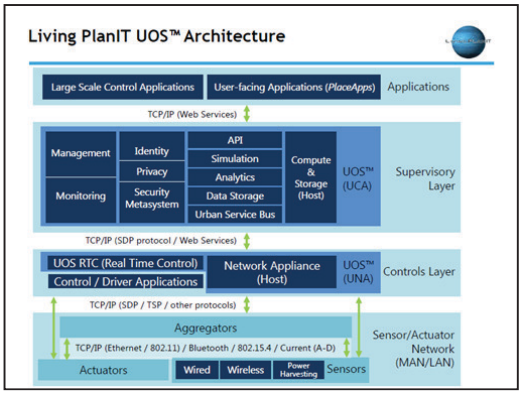


Figure 3 Living PlanIT Urban OS Architecture

With an open Applications Programming Interface (OpenAPI) approach, the premise is that end-use applications will be written by partners who are best in class.

LGCNS (LGCNS 2013) has developed a Smart Green City Solution which uses ICT as an integrator for city services. It includes Digital Signage, Environmental Monitoring, Intelligent Traffic, Intelligent Street lighting, Smart Metering, Smart green homes, Smart Green Buildings, Smart Grid, New and Renewable Energies, Water Management, Maintenance, Operations, Surveillance and finally an Integrated Control Center similar to IBM to pull it altogether. The solution enables a variety of devices and facilities to be controlled by a single system just like a computer OS facilitates and hardware components.



Figure 4 LGCNS Smart City Solution

PROPOSED FRAMEWORK

Based on the various efforts that have been observed, it is proposed to have a unifying approach. Consider a set of foundational pillars (Buildings, Utilities & Energy, Mobility and Water), which are integrated by several layers of ICT centric technologies. This enables the cross-fertilization of combined solutions transcending multiple verticals for example, Energy and Water, Mobility and Water, Buildings, Energy and Mobility. This will lead to a true optimized citywide solution.

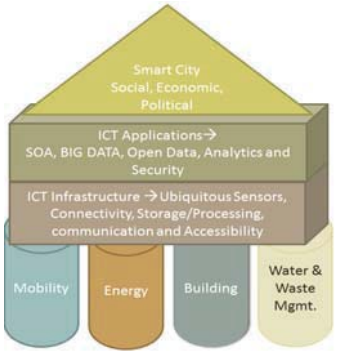


Figure 5 Proposed ICT based Framework for Smart Cities

Since the four pillars have been discussed at length in this paper we shall now focus on the three ICT layers.
(1) ICT Infrastructure
(2) ICT Core Applications
(3) End User Applications and Experiences.

ICT Infrastructure This layer is the interfaces with the core pillar of proposed architecture in the bottom and supports the ICT application layer on the top. The main functions of this layer are the following:

Sensors and their networks: The Sensors are hardware devices, which monitors different resources. These sensors are built in such way that these perform without notifying their presence in a system. These are tailored and customized for a particular purpose. The sensors are categorized broadly into two groups. They are (1) Homogeneous sensor: group of sensors of same purpose and interface (2) Heterogeneous sensors: group of sensors having different purpose and interfaces. In Smart City perspective, sensors constitute a smart environment (Filipponi, Vitaletti et al. 2010). It provides an eco-system in which different objects interact with each other. The major use of sensors in ICT infrastructure layer is monitoring and control. The most recent development of sensors for the Smartcities are categorized as Ubiquitous Sensor Networks (USN) (Hernández-Muñoz, Vercher et al. 2011) .

Communications and connectivity: Communications form the nervous system of ICT infrastructure. With 4th Generation (4G) of telecom technology, Smart cities have access to enormous bandwidth, which can support wide range of ICT applications. As the cost of deployment of a communication technology in a smart city is a huge cost, pre-planning and choice of technology may reduce the initial cost of deployment. This requires a fine-grained calculation of bandwidth and connectivity requirement of a smart city ahead of its deployment. At the same time, low-power, low bandwidth wireless networks like Zigbee are developed exclusive for such ubiquitous indoor wireless networks. And devices such as gateways and edge-routers (Jiang, Dawson-Haggerty et al. 2009) are used for necessitating low power wireless personal area networks (LoWPAN) onto Wide area network (WAN).

Storage/Processing: With recent advancement in ICT, we notice a paradigm shift in the way people use the computing resources. Laptops and Desktops are being replaced by the large-scale server farms. There are some fundamental challenges in these models. They are (1) storage (2) processing (3) security, (4) latency and (5) Power. The solutions to first three changes are dependent on innovation in datacentres across the globe but the later two are dependent on the location of the datacentre. The

latency of any application increases with increase in distance from user to the datacentre, which host the application. Therefore, the Smart city design should incorporate scope for large-scale data centre, which can host city specific application with low latency. The power consumption in modern datacentre is in range of Mega Watts of energy, so the energy planning of smart city should take into account this requirement.

ICT Applications are mainly divided into two groups. They are (1) Core applications (2) User applications.

The core applications are used for monitoring, maintenance and proper functioning of the Smart cities. These applications provides interface to the ICT infrastructure layer. The major functions are data gathering, storage, security and accessibility. The core applications will need to be provided by various agencies. For example, an energy agency can provide interfaces to access various energy level data such as available energy, predicted generation capacity. The transportation agency can provide the interfaces to for retrieving data about current traffic conditions, any breakage in metro rail, current petroleum price, cost, schedule of bus, bus fare etc. The building department can provide the data related to current occupancy in each building, surrounding conditions (temperature, humidity).

The user level applications will be developed by commercial or non-commercial entities (such as University labs, open source communities) using these interfaces. For example, an optimal route application may need to use interface provided by transportation agency, energy agency and building department to combine the data received from all these sources and decide optimally which is the best route and mode to move from one location of the city to another location. Such a framework will allow innovative companies and services to come up using the core application framework.

End-Use Applications & Experiences Technology and its underpinnings (or overpinning in terms of applications) carry little or no meaning to the average citizen or public who benefits from it. People can relate to technology only in terms of what they experience in their daily lives and can be epitomized in the form of "end-user experiences". Each end-user experience will be based on a set of vertical "industry" or "context" specific solutions. Some examples include:

- Building Management Solutions
- Green focused Social Applications
- Smart Homes
- Smart Office Solutions
- Smart Car Park Management
- Smart Water
- Smart Hospitals

CONCLUSION

Information is power & leverage this power of information technology is wisdom. Such information would also enable people and managers of the city to benchmark their sustainable practices with their counterpart cities and thus develop best practices and breed sustainable policies.

This paper has discussed the 4 pivotal pillars related to cities – Buildings, Utilities & Energy, Mobility and Water. In order to integrate these pillars into a comprehensive city solution, ICT is seen as the unification layer. The ICT aspects have been broken into 3 layers – starting with the infrastructure, core applications and finally the "visible" end user applications and experiences.

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TECHNICAL, ECONOMIC AND ENVIRONMENTAL ADVANTAGES OF USING INTERNAL WALLS OF BUILDINGS IN MASONRY GYPSUM BLOCKS

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ABSTRACT

The masonry walls in gypsum blocks have advantages over traditional masonry in block ceramics and concrete with respect to structure's weight and dimensions in the flat area; ease of embedding facilities, productivity and reduction of construction stages.

Despite these advantages, few companies use this type of masonry. A major reason stems from limited knowledge of the performance of this subsystem in buildings, lack of technical knowledge and design execution and case examples that show satisfactory results with application of sealing technology.

This paper presents a technical, economic and environmental comparative approach regarding the production of CO2 at various stages of production (manufacturing and application) between the analyzed masonries.

INTRODUCTION

When technically well built, respecting the limit of the material and the sealing system and the interaction with other systems of a building, the internal gypsum walls provide significant advantages when compared with the construction of masonry walls, ceramic and / or concrete. From the technical point of view the following advantages exist: a) has a higher mechanical strength, b) can be applied to the finished floor without the need to perforate c) can be easily removed without leaving marks d) have a higher thermal and acoustic insulation by unit thickness, e) reduce weight in structural elements. From the economic point of view, the following advantages exist: a) higher productivity and lower overall cost in construction, b) larger dimensions of the internal spaces, c) lower construction area. From an environmental standpoint, the advantages are: a) output produce less CO2 per unit constructed area, b) a lower environmental degradation per unit volume and production of materials and constituent components, c) and low power (kW / h) used during production and transport of constituent materials. This paper presents the main elements that should be considered in the development of masonry design, with gypsum inside and the main characteristics of the impact comparing the technical, economic and environmental impact of internal constructed gypsum blocks of masonry and concrete blocks and / or ceramic, based on research production of materials used in the construction of such systems.

COMPARATIVE ASPECTS BETWEEN TYPES OF MASONRY

Compressive behavior

The masonry gypsum blocks are lightweight, ranging from 0.6 to 1.0 kN/m^2, when compared to traditional masonry of the ceramic blocks ranging between 1.2 KN / m^2 to 1, 8 KN / m^2, contributing to reduction of loads on the structure. This reduction also influences the decrease of arrows immediate and creep of concrete slabs and beams.

With respect to compressive strength and modulus of elasticity, PIRES SOBRINHO (2007) conducted tests on small walls of dimensions 0.6 m x 1.2 m, whose characteristics and test results are shown in Table 1.

It was observed that the walls of gypsum blocks have rigidity 69% greater than the ceramic block masonry coated with mortar and should thus focus voltages in equal proportion. On the other hand, the resistance of the masonry blocks of 10 cm thick gypsum has twice the capacity resistant walls, responding satisfactorily in the global behavior.

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Table 1
Characteristics and test results of small walls

Element	Bedding mortar	Coating	Total Thickness	Rupture load (kN)	Rupture Stress(MPa)	Stiffness* (kN.m/m)
Gypsum block	adhesive plaste	gypsum coating	10 cm	21,40	3,57	81.000
Ceramic block	Mixed mortar cement and lime	Roughcast in two faces	10 cm	8,49	1,41	21.600
Ceramic block	Mixed mortar cement and lime	Roughcast and mixed mortar cement and lime	13 cm	15,65	1,74	48.000

Structural behavior

In order to compare the influence of both types of internal masonry (gypsum and ceramics) in buildings, cases were analyzed in the computational model of a structure sizing. Thus, we kept the dimensions and positions of structural elements (columns, beams and slabs) and changes were observed in the bars of pillars and beams, keeping the forms of these elements (Ciarlini, et al 2001).

The analyzed building has six apartments per floor. Each apartment consists of living room, bedroom, bathroom and kitchen, with a total blade 17.05 m by 15.30 m. Figure 1 shows the surface pattern of the analyzed building.

In analyzing the behavior of the structure usual procedures were followed for design, analysis and detailing of reinforced concrete structures, respecting the provisions of the relevant technical standards, especially those of NBR-6118/80 - "Analysis and execution of structures concrete ", NBR - 6120/80" Loads for the analysis of structures "and NBR - 6123/87 -"Wind on buildings", considering a basic wind speed (V0) of 30 m / s.
Also considered were five types of flooring vertical: 6, 10, 14, 18 and 22 decks, all with the same floor plan. A comparison of foundations for these loads in buildings has been made considering only vertical loads, since the horizontal loads and bending moments were the same in all cases.

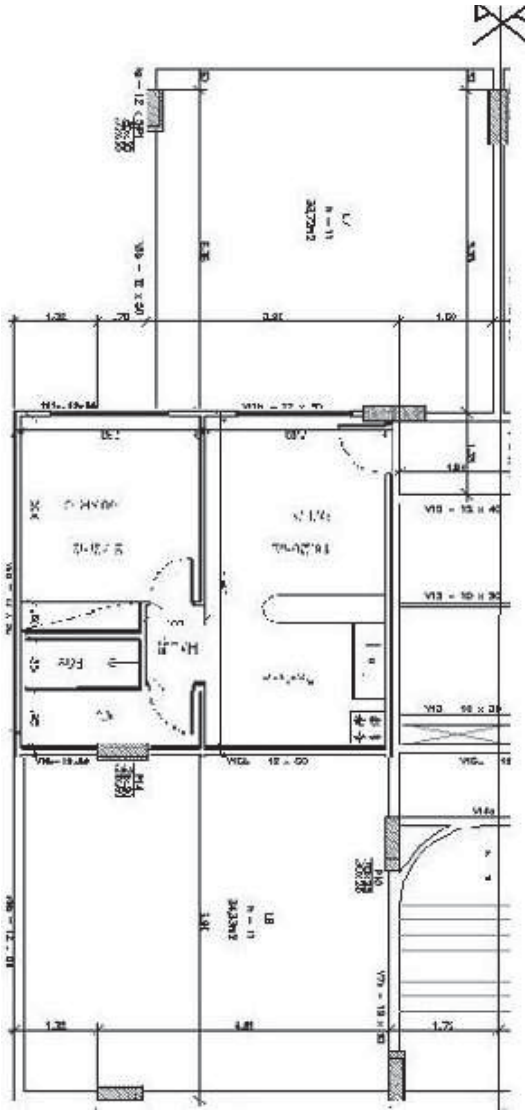


Figure 1 - symmetric part of the plant's structural deck analyzed building

Table 2 shows the results of the quantitative total loads on foundations, the armor of the structure and volume of concrete foundation, as well as cost analysis, based on cost table in 2009.

In this table, the indication of type 6, 10, 14, 18 and 22, relates to buildings with 6, 10, 14, 18 and 22 floors with ceramic masonry, the inner and outer walls.

The indicated types 6G, 10G, 14G, 18G and 22G refer to buildings with 6, 10, 14, 18 and 22 floors with internal walls and external gypsum blocks with ceramic blocks.

Table 2
Quantitative and cost analysis

Type	Steel frame			concrete foundation			Loads foundations
	(t)	(U$) x 10^3	%	(m^3)	(U$) x 10^3	%	
6	17	55,2		41,9	25,1		1.386
6G	15	48,7	-11,8	30,9	18,5	-35,6	1.158
10	35	113,7		101,7	61,0		2.697
10G	30	97,5	-14,3	78,3	47,0	-29,8	2.308
14	55	178,7		166,0	99,6		3.927
14G	49	159,2	-12,2	125,8	75,4	-32,0	3.315
18	84	273,0		238,6	143,2		5.093
18G	72	234,0	-14,3	180,5	108,3	-32,2	4.317
22	114	370,5		323,0	193,8		6.282
22G	101	328,2	-11,4	244,6	146,8	-32,0	5.309

The results show that it is possible to reduce an average of 15% of the total loads on the foundation with the use of internal walls on masonry gypsum block replacing the traditional walls with ceramics block.

Economic comparison

Economies of cost and time produced with the technological option of using internal walls of masonry gypsum blocks to replace the traditional masonry can also be evaluated.

Regarding the economy in structure, table 2 shows that it is possible to reduce from 11.8% to 14.3% of the cost of the superstructure between 29.8% to 35.6% in the foundation.

With regard to implementation, Table 3 shows that the productivity of services in masonry walls finished gypsum blocks is 67% greater than all the services required to complete the walls of ceramic bricks.

It is worth noting that the gypsum walls feature a number of activities, a movement of material in the construction, and the total time of much lower activity.

Table 3

Productivity in the activities of the internal masonry

System	**Services involved**	**Productivity (h / m^2)**	**time for finished service (h/ m^2)**
Masonry in ceramics block	Elevation (marking, elevation, piping and electrical)	0,45	1,13
	Roughcast	0,08	
	coating	0,45	
	preparation and painting	0,15	
Masonry in gypsum block	Elevation (marking, elevation, piping and electrical)	0,56	0,68
	preparation and painting	0,12	

In the assessment of unit costs for direct service delivery, the difference is not significant; being 5.2% in favor of traditional masonry block ceramic coated with mortar, see Table 4.

However, taking into account the area gain, around 2.3%, the smallest thickness and the possibility of being able to build the floor covering before the execution of the masonry walls in gypsum blocks with sensitive savings on materials and labor, the advantages of this system is much higher.

Table 4

Unit costs for the implementation of systems

System	Involved services	Unit Cost (U$ / m^2)	Total Cost (U$ / m2)
Masonry in ceramics block	Elevation (marking, elevation, piping and electrical)	12,30	21,62
	Roughcast	0,85	
	coating	4,19	
	preparation and painting	4,29	
Masonry in gypsum block	Elevation (marking, elevation, piping and electrical)	19,11	22,76
	preparation and painting	3,65	

CONSTRUCTION SYSTEM OF INTERNAL WALLS IN MASONRY BLOCK OF GYPSUM

This construction system consists of interlocking blocks precast with nominal dimensions of 50 cm x 66.7 cm x esp. The thicknesses are 7cm (tubular or compact) and 10cm (compact) together with a thin layer of adhesive gypsum.

Constructive Aspects

The main technical characteristics of the masonry in block of gypsum are:

• Large Size (three blocks form a square meter of area), with increasing productivity;

• Millimeter Accuracy, with flat surfaces and fitting type male-female, facilitates the raising of the walls, the conference alignment and flatness;

• The union of the blocks is done with a thin layer of adhesive gypsum, requiring no gasket thickness control;

• Allows cutting with a saw with practicality and accuracy, the leftovers are easily reused in own elevation, generating little waste;

• Electrical installations can follow the empty blocks or tears in the masonry;

• Increasing productivity and reducing block fragment on floors;

• The adhesive gypsum blocks have excellent adhesion between the gypsum and other materials (concrete, ceramics, wood, fibrous materials, etc.);

• Avoid direct contact between components of gypsum with steel components.

Design details

The development of a design to produce internal walls of buildings plays an important role in the performance of the building system and integration with other designs that make up the building.

Design development can interact with other designs (architectural installations, structural and cladding) and conforming to the interfaces of the systems and subsystems of the building.

There are some important principles to be considered in developing design masonry gypsum:

• It is necessary to know the deformation potential of the structure to avoid concentrating too much effort (above the service limit) and / or in the walls. With this data, it becomes possible to measure fasteners and bearing capacity of the masonry.

• Consider the limits and application system. Technical aspects presented in THIEBAUT (1999) and DOMINGUEZ & SANTOS (2001), can be taken as reference.

• Consider the design of masonry as optimized case of other designs that make up the building.

• Modulating the walls in order to utilize the greater number of entire blocks, avoiding tying below the minimum required; initiate disposition of the blocks doorways and determine the use of spars.

• Analyze the links between forms of gypsum block walls with masonry boundary and structural elements (columns, beams and slabs).

• Detail sealing using types of blocks with hydrophobic characteristics to the first row and wet areas.

• Detail the fixing frames, paintings and frame the electrical elements.

• Position the walls, as axle or shaft structure suitable for masonry.

ASPECTS OF SUSTAINABILITY

In benchmarking among construction systems used in the construction of internal s of the apartments in the structural model analysis.

There are 6 apartments per floor, each with an area of 30.2 m^2. The quantification of the walls that make up an apartment were analyzed in two cases:

Case 1: walls in ceramic blocks (19x19x) cm, settlers and coated with mortar mixed cement and lime 1:2:8, internal coating with thickness 2cm on each side, totaling 13cm, see figure 2.

Internal wall area: total = 55.80 m^2, external wall area = 30.47 m^2 (for an apartment)

Estimated weight the of masonry walls with block coated with ceramic mortar (esp = 13cm) = (55.80 +30.47) x 140 = 12.08 kg/m^2 pav ton x 6 = 72.48 ton / pav

Activities used:
Area to store sand = 27 m^3 / pav area occupies 11 m^2/pav
Area to store bags of cement (50kg) = 216 sc / pav = 3.5 m^2
Area to store bags of lime (40kg) = 270 sc / pav = 6.5 m^2
Area to store of ceramic blocks = 10.400blocos = 37, 44 m2 = 58, 44 m2/pav
Mixture (use mixer) 2.05 Kw; winch load 75kW =77.05 Kw / pav

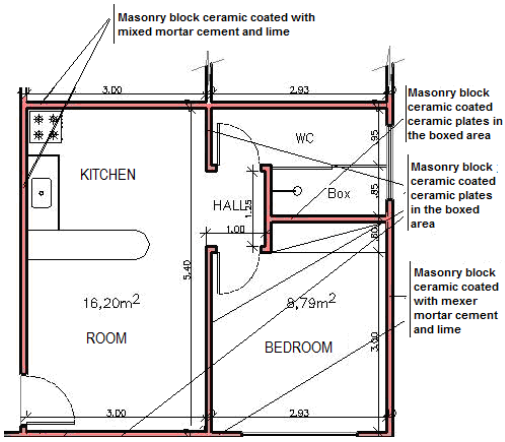


Figure 2 - Aspects of conventional construction (masonry ceramic blocks and cement mortar)

Case 2:Internal walls in masonry gypsum blocks (66,6 x50, 0x7, 0) cm, coated with gypsum slurry but dry areas, 5mm each side, and ceramic tile in wet areas fixed with adhesive gypsum. The external walls in the conventional system are shown in Figure 3.

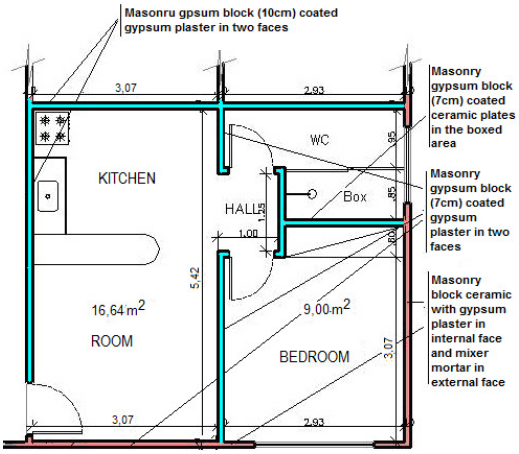


Figure 3 - constructive aspects of the system of internal with gypsum blocks

Internal wall area = 30.13 m^2 with gypsum blocks of the7cm and internal wall area=26, 67 m^2 with gypsum block of the 10cm and external wall area = 30.47 m^2 with ceramic block coated with mixed mortar in external face and coated with gypsum in internal face.
Estimated weight of the masonry walls gypsum blocks = (30.13+26.67x45*102) =4.07+ 4.27 kg/m^2 = 8.34 ton x 6 pav = 50.04 ton / pav (30% lower)

Activities used:
Area to store of gypsum blocks = 24 m^3 / pav area occupies 8 m^2/pav
Area to store bags of adhesive gypsum (20kg) = 151 sc / pav = 7.5 m^2
Area to store sand = 8.4 m^3/ pav area occupies 3.4 m^2/pav
Area to store bags of cement (50kg) = 67 sc / pav = 1.1 m^2
Area to store bags of lime (40kg) = 83 sc / pav = 2.0 m^2
Area to store of ceramic blocks = 3.300blocos = 11.62 m^2 = 33, 52 m^2/pav (43% less)
Mixture (use mixer) Kw = 0.64; Winch load = 75kW = 28.50 Kw / pav (63% less)

The utilized energy is a way to measure the environmental impact of buildings (ABEYSUNDARA et al 2008), which is considered an indicator of sustainability of buildings. This energy considers all energy used in manufacturing, transportation and use of materials in construction.
Table 5 shows a comparative of the energy function incorporated in relation only to the frame pillar of the superstructure of the concrete foundation and the masonry of the apartments to the building dimensioned to 6, 14, 22 floors, which is constructed based on unit values Energy Incorporated presented by TAVARES (2006).

Also in this table, the indication of type 6, 14 and 22 refers to buildings with 6, 14, 22 floors with ceramic masonry, the inner and outer walls.

The indicated types 6G, 10G, 14G, 18G and 22G refer to buildings with 6, 14, 22 floors with internal walls and external gypsum blocks with ceramic blocks.

Table 5 - Comparative analysis on the basis of the energy use

Type	Steel frame			Foundation concrete			Internal masonry			Totalization	
	Weight (t)	EE (GJ)	%	Vol (m3)	EE (GJ)	%	Peso (t)	EE (GJ)	%	EE (GJ)	%
6	17	510		41,9	311,7		434,88	1100		822,8	
6G	15	450	-11,8	30,9	229,9	-26,3	300,24	975	-11,4	680,9	-17,3
14	55	1650		166,02	1235,2		1014,72	2567		2887,8	
14G	49	1470	-10,9	125,79	935,9	-24,2	700,56	2275	-11,4	2408,2	-16,6
22	114	3420		322,96	2402,8		1594,56	4034		5826,9	
22G	101	3030	-11,4	244,62	1820,0	-24,3	1100,88	3575	-11,4	4853,6	-16,7

CONCLUSIONS

When comparing the influence of masonry ceramic and masonry gypsum in structured concrete buildings, the advantages of using masonry block gypsum produces reduction of about 14% of the frames of the superstructure and about 32% of the concrete use. In addition, there is a 66% increase in productivity, waste reduction of approximately 75%, a 63% reduction in the energy used in the production of construction and 45% water used in the application process between these systems.

The use of walls in masonry, gypsum is still rarely used in Brazil, although it is a traditional practice in European countries, due to the reduced knowledge of technical elements of this type of system.

In tall buildings built in the post-occupational metropolitan area of Recife, in 15 ventures, the oldest with more than 20 years, there are few pathological manifestations.

The technical advantages, economic and environmental problems are significant and can be considered a viable alternative to the use of this system in business or residential buildings.

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ASSESSMENT OF NATURAL VENTILATION POTENTIALS ON FREE-FORM ARCHITECTURE DESIGN USING CFD SIMULATIONS: A LEARNING HUB BUILDING IN SINGAPORE

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ABSTRACT

This research focuses on an effort to demonstrate a case study of CFD approach to natural ventilation evaluation in freeform architecture design in Tropics. We first constructed the CFD models based on three building design configurations and then compared. Thereby, the complicated building geometry together with the CFD modelling issues (domain setting and model simplification) was investigated. Subsequently, steady state, k-ε turbulence model and incompressible flow of a constant property fluid was considered. Furthermore, climate information (wind directions, temperature, and solar heat gain), urban context (surrounding building masses and distribution), and time and season-based changes were collected and evaluated. CFD simulation was performed along with the whole design process iteratively to optimize the natural ventilation as well as the architecture design. The result of this study is expected to serve as a solid basis for the CFD application to optimize the natural ventilation and create innovate ventilation strategies, and hence to achieve sustainability in building designs without compromising the novel architecture design potentials.

INTRODUCTION

In the past decades, air-conditioning systems were predominately conducted in Singapore. However, the increased focus on climate change and sustainability has encouraged people to reconsider the deployment of natural ventilation in buildings in terms of energy efficiency. Furthermore, Computational Fluid Dynamics (CFD) simulation has been increasingly employed for predicting building airflows and testing natural ventilation strategies [1-3]. On the other hand, in recent years, new possibilities have emerged to allow the architects and structure engineers to further explore novel architecture forms and design based on advancements in AEC (architecture, engineering, and construction). Therefore, the evaluation and prediction of building performance with CFD in design phase will be a great challenge.

The present study focuses on an effort to demonstrate a case study of CFD approach to natural ventilation evaluation in freeform architecture design in a challenging climate zone, namely the hot-humid climate in Singapore. We first investigated the CFD modelling issues (e.g. domain setting and model simplification) to better construct the CFD model in terms of the complicated geometry. Subsequently, steady, k-ε turbulence model and incompressible flow of a constant property fluid were considered. Furthermore, climate information (wind directions, temperature, and solar heat gain), urban context (surrounding building masses and distribution), and season-based changes were collected and evaluated. CFD simulation was performed along with the whole design process iteratively to optimize the natural ventilation as well as the architecture design. The result of this study is expected to serve as a solid basis for the CFD application to optimize the natural ventilation and create innovate ventilation strategies, and hence to achieve sustainability in building designs without compromising the novel architecture design potentials.

In this paper, level 1, 2, 3 … 9 are named as L1, L2, L3… L9. North wind, northeast wind, south wind and southeast wind are named as N-Wind, NE-Wind, S-Wind and SE-Wind. Point a, b, c and d are named as P-a, P-b, P-c and P-d.

APPROACH

Case Study: Learning Hub in NTU Campus

The case study project is Learning Hub, an educational facility designed and built for Nanyang Technological University (NTU) in Singapore as shown in Figure 1 [4]. The building design was completed in Oct 2012 with CFD evaluation started from March to October 2012. Currently it is under construction.

This hub has 9 stories with total height 34.2 meters, and each level has 3.8 meters height. It is designed with a structure without conventional corridors. As a flower like layout, it is made up with several “petals” (involving 55 tutorial rooms), atrium and 3 staircase blocks, as shown in Figure 3. In L1, there are only

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petals in the north, south and west side. From L2 to L6, there are 13 petals. In L7, L8 and L9, there are 10, 6 and 4 petals respectively.

Also, it allows the students enter from all directions around into a large central space which links all the separate "petals" together. The classrooms are stacked into each "petal" tower and build up gradually. Gardens, shaded terraces, and pergolas are on selected upper levels and rooftops, as shown in Figure 1. All the rooms are air-conditioned. On the other hand, the public spaces (e.g. the corridors and atrium area) are designed to be naturally ventilated.



Figure 1 Impression drawing of Learning Hub [4]

The main objective is to explore the effect of atrium design on the natural ventilation performance of Learning Hub. Thereby, four wind directions and seasonal changes are considered. We mainly focus on the following questions: i) Atrium and openings are considered as a good design to facilitate the natural ventilation in structured buildings. However, how good can the atrium design and openings help to improve the natural ventilation in such freeform architecture? and, ii) what are the implications of such freeform architecture design in Tropics in terms of natural ventilation? Thus, three cases were studied and then compared, namely Base Case, Variant I, and Variant II.

These three simulation cases are illustrated in Figure 2 and descripted in Table 1. The difference between Base Case and Variant II is that there is an atrium in Variant II but no atrium in Base Case. As illustrated in Figure 3, there are 3 staircases and 10 gaps in this building. The difference between Variant II and I is that, the gaps between blocks and staircases are closed in Variant I, but 50% meshed in Variant II. In another words, there is C-Ventialtion in Variant II but not in Variant I from L2 to L6.

All the simulation cases are shown in Table 1, which include two design models and four wind directions N-Wind, NE-Wind, S-Wind and SE-Wind.

In order to measure the performance of natural ventilation within atrium, two parameters are used here, which are:

- Volume weighted average velocity magnitude within the atrium. It is based on the volume of whole atrium from ground level up to level 9. The total height of the atrium is 34.2 meters.
- Velocity magnitude of 4 points on each level. The 4 points are indicated in Figure 3 as P-a, P-b, P-c and P-d. in the following paper. P-a is the centre point of atrium area where there is no people activates. P-b, P-c and P-d are located in the corridor area where lots of human activities happen.

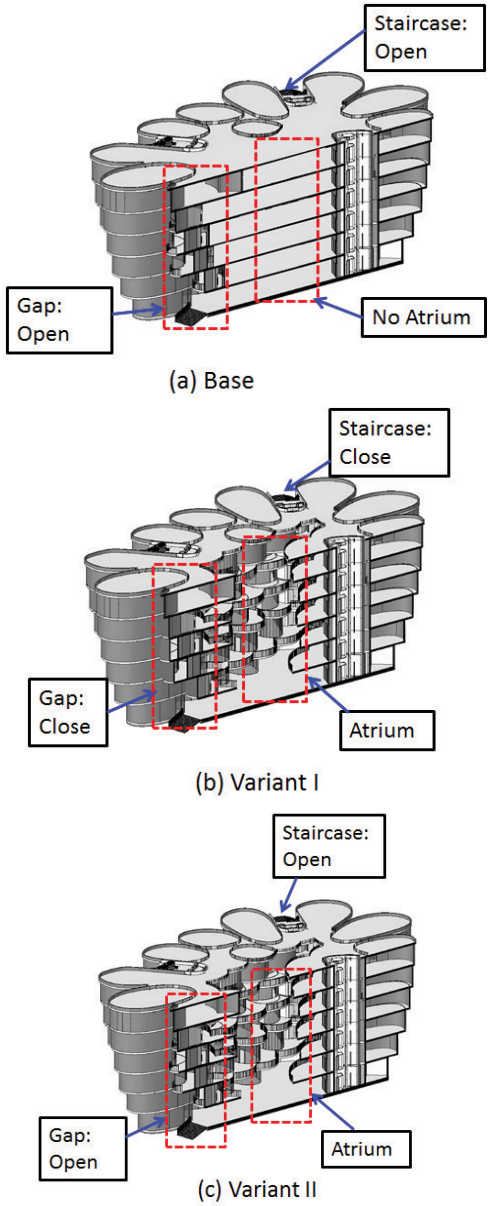


Figure 2 Cross section view of 3 models: (a) Base, (b) Variant I and (c) Variant II.

Table 1
Matrix of 3 simulation cases

	Base Case	Variant I	Variant II
Atrium	No	Yes	Yes
Gaps	Open	Close	Open
Staircases	Open	Close	Open

CFD Model Description

The computational model is illustrated in Figure 4. The domain is a cubic with dimension 1000 m × 1000 m × 500 m. The Learning Hub model and its surrounding buildings are located in the centre of the domain.

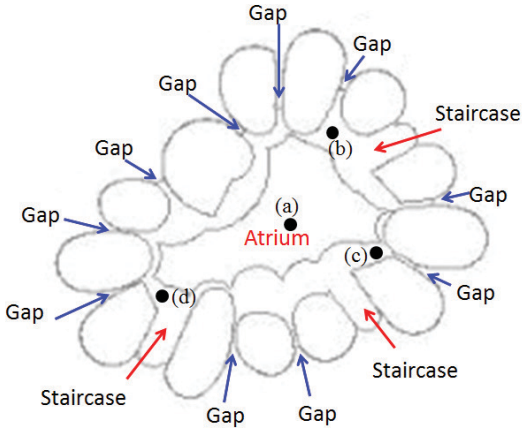


Figure 3 An example of positions of atrium, gaps and staircases together with four selected measured points in computational model (level 5).

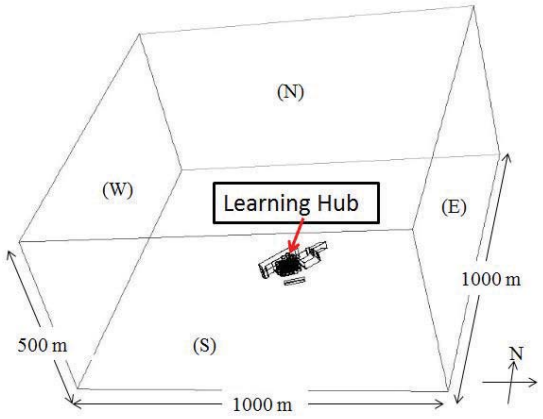


Figure 4 Geometry of the computational domain.

Figure 3 is the top view of the Learning Hub computational model. In order to build up the simulation model, following assumptions are made.

1) The ground is assumed to be a flat surface;
2) The height differences between Learning Hub and surrounding buildings are considered.
3) The envelope of staircases is assumed to be a porous face with 50% porosity for Base Case and Variant II.

Turbulent Model

The turbulence models were divided into two groups: large-eddy simulations (LES), and turbulent transport model (Reynolds averaged Navier-Stocke equation modelling, RANS). Generally, LES model provides much more information about the flow field and the dispersion process than the RANS approach which directly gives only the mean field and provides only statistical estimates for the turbulent transport. This has been proven in many areas [5-7]. However, LES requires finer grid distribution which will increase the computing time dramatically. RANS models are the two-equation turbulence models, k-ε and k-ω models in which k represent the turbulent kinetic energy, ε is the turbulent dissipation rate and ω is specific dissipation rate. The k-ε models can be separated into standard model, renormalization group theory (RNG) model and realizable model. RNG model performs better than standard k-ε model near wall surfaces [8]. Also, RNG model provides reasonable accuracy compared to large-eddy simulation (LES) that is more computational intensive but with higher accuracy. In order to make the results as accurate as possible and save computational time at the same time, RNG k- ε model is used in this paper.

Radiation Model

In order to calculate the solar heat gains, the position of the sun in the sky, solar intensity, and the thermal radiation exchange between each building envelope element and the surroundings, must be calculated [9]. Fluent offers the Solar Ray Tracing model which helps to calculate the direction of solar radiation. The time selected was 13:00 on 21st June, which represented the peak solar load time in Singapore. In order to calculate the thermal radiation exchange, the Discrete Ordinates model was used. The radiation model was only used in Case II, where the buoyancy effect was included.

Wind Data in Singapore

In Singapore, there are four prevailing winds: N-Wind, NE-Wind, S-Wind and SE-Wind. The average wind speed are 2 m/s, 2.9 m/s, 2.8 m/s and 3.2 m/s accordingly. According to the statistics by National Environmental Authority of Singapore [10], N-Wind and NE-Wind prevail from December to March, and S-Wind and SE-Wind prevail from May to September; in the months of April, October and November, the wind directions are various. In this paper, we assumed that, in April, October and November the time are evenly shared by all four prevailing winds; N-Wind and NE-Wind evenly

share the time from December to March; and the same assumption was applied to S-Wind and SE-Wind. Therefore, the frequencies for N/NE wind and S/SE wind in a year are 22.9% and 27.1%.

Boundary Conditions

External climate affects the ventilation profiles inside the building, especially when it is natural ventilation. For wind driven ventilation, the most important weather factor is the wind condition including the wind direction, speed and frequency. For buoyancy driven ventilation, the outdoor air temperature, solar radiation and other heat sources inside the building are important weather data. In this model, solar radiation is the only heat source for buoyancy driven ventilation.

The faces (N), (E), (S) and (W) indicated in Figure 4 are north face, east face, south face and west face for the cubic domain. Except these four faces, the top face and bottom face represents the sky and the ground, which were set as symmetry and wall in the boundary condition accordingly. The boundary conditions for faces (N), (E), (S) and (W) varied accordingly, as shown in Table 2. Inside the domain, all the boundaries except the staircases and gaps in between "petals" were modelled as no-slip wall boundaries with zero heat flux. The staircases and gaps in between "petals" were modelled as porous jump boundaries with 50% porosity. Fluent offers kinds of calculations for inertial resistance coefficient. In the present work, a solid plate with holes model is used [11]. The thickness of the surface was assumed to be 0.1 m and C_2 calculated is 31.24 /m.

Table 2
Boundaries conditions for four wind scenarios.

Faces	N-Wind	NE-Wind	S-Wind	SE-Wind
(N)	Velocity inlet	Velocity inlet	Pressure Outlet	Pressure Outlet
(E)	Pressure Outlet	Velocity inlet	Pressure Outlet	Velocity inlet
(S)	Pressure Outlet	Pressure Outlet	Velocity inlet	Velocity inlet
(w)	Pressure Outlet	Pressure Outlet	Pressure Outlet	Pressure Outlet

RESULTS AND DISCUSSIONS

The types of natural ventilation driving forces are summarized in Table 3. In Base Case, wind-driven ventilation which is also cross ventilation dominates; in Variant II, there are two driving forces, wind and buoyancy effect, which is hybrid ventilation; in Variant I, buoyancy driven ventilation dominates from L2 to L6 and hybrid ventilation dominates the other levels. Figure 5 is an example of velocity contours in nine levels.

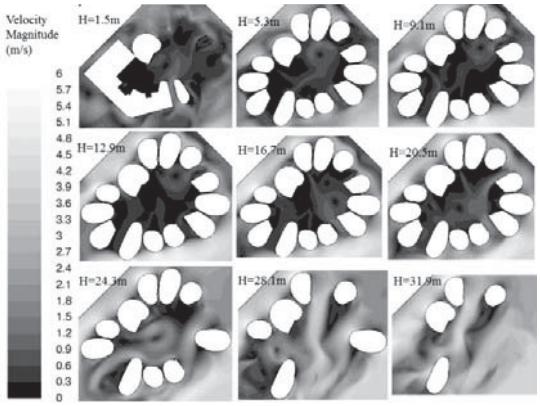


Figure 5 Velocity contours in 9 levels for Base Case NE-Wind.

Effect of wind directions on atrium natural ventilation

As shown in Table 3, for all 3 cases, when the wind blows from southeast, the volume-weighted average velocity within the atrium has the highest value, followed by northeast wind, south wind and north wind. This matches the sequence of input where the southeast wind has the highest average wind speed 3.2 m/s, followed by northeast wind 2.9 m/s, south wind 2.8 m/s and north wind has the lowest average wind speed 2 m/s.

Table 3
Volume-weighted average velocity of 3 cases.

Speed (m/s)	Base Case	Variant I	Variant II
N-Wind	1.14	1.61	1.63
NE-Wind	2.14	1.86	1.91
S-Wing	1.75	1.73	1.91
SE-Wind	2.22	1.86	2.13
Average in a year	1.83	1.77	1.91

The effect of wind directions in various locations is summarized in Table 4. Inside the Table 4, the black dot means that in certain wind direction, the wind speed in certain location is larger than 0.6 m/s, which is one requirement for human comfort [12] in Singapore.

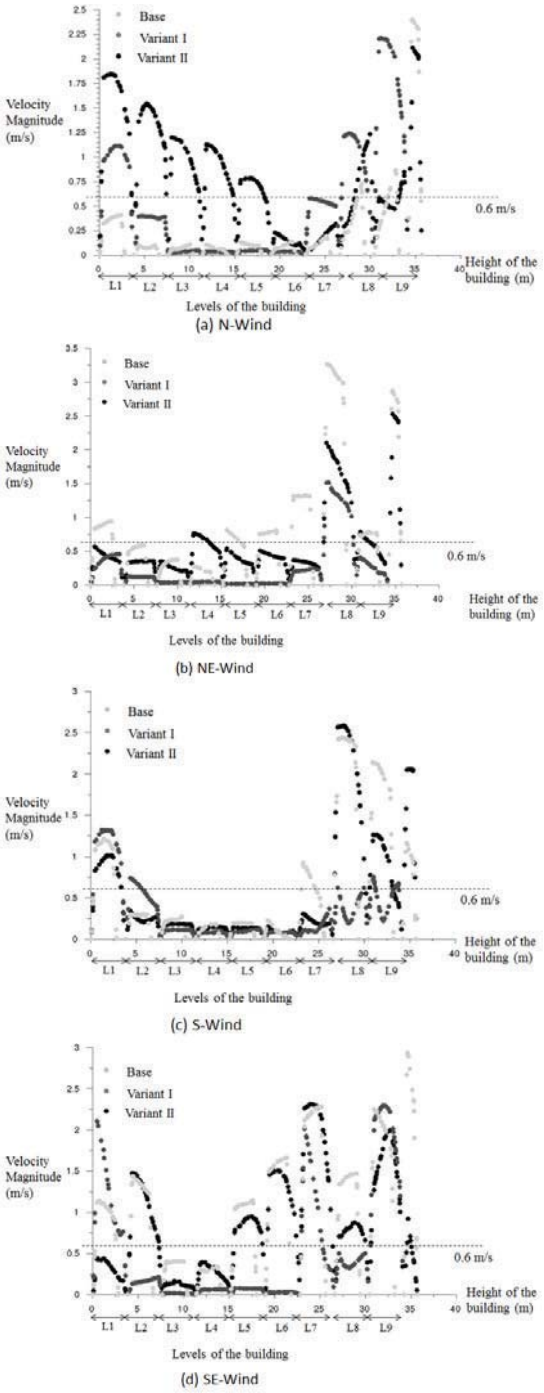


Figure 6 Velocity magnitude plot on Line-a for (a) N-Wind, (b) NE-Wind, (c) S-Wind and (d) SE-Wind.

As mentioned above, P-a is located in the centre of atrium, and P-b, P-c and P-d are located in different corners where are corridors. From the Table 4, we can see that, in all 3 cases, the performance of natural ventilation from level 2 to level 6 is the worst compared with the other levels, where almost no wind scenario could match the human comfort standard in the corridor. The performance of cross ventilation becomes better from level 7 and above. The main reason is that some blocks are removed from level 7 and above, which is shown in Figure 5 clearly. This enhance the cross ventilation. Level 1 is the ground floor and lots of people activities happen here. For both two cases, either N/NE wind or S/SE wind helps to reach the human comfort level in P-a, P-b and P-c. P-d locates in the deep corner and no cross ventilation could happen here.

All the wind directions do not exist all the time in a year but are seasonal. From December to March, N/NE wind dominates; and from May to September, S/SE wind dominates. Therefore, even though the average wind speed at certain point can be larger than 0.6 m/s for certain wind scenario, this can only happen in certain month not whole year.

Effect of atrium design on atrium natural ventilation

The Base Case is without atrium case and Variant II is the one with atrium, and all the other designs for both cases are the same. By comparing Base case and Variant II, it is shown in Table 3 that, for N-Wind and S-Wind, the volume-weighted average wind velocity of atrium is increased by 43.0% and 9.1% accordingly, after adding the atrium. However, the volume-weighted average wind velocity of atrium is decreased by 10.7% and 4.1% for NE-Wind and SE-Wind. For north monsoon which include north wind and northeast wind, the average wind velocity in atrium is increased by 7.9%, after adding the atrium. Similarly, for the south monsoon, the average wind velocity is increased by 2%. In a year, the time percentage for north and south monsoon is 22.9% and 27.1%. Therefore, the average wind velocity in the atrium is 1.83 and 1.91 m/s, for Base Case and Variant II. Therefore, in a year, the volume-weighted average velocity in atrium is increased by 4.4% by adding the atrium, in such a freeform architecture design.

The difference between Variant I and II is that the staircases and gaps between blocks are closed for Variant I and open for Variant II. In another word, from level 2 to level 6, it is hybrid ventilation in Variant II and only wind driven ventilation in Variant I. By comparing these two cases, the volume-weighted average wind velocity of atrium is increased by 1.24%, 2.69%, 10.4% and 14.52% for N-Wind, NE-Wind, S-Wind and SE-Wind separately. In a year, the volume-weighted average velocity in atrium is increased by 7.91% by adding openings in the building.

From Table 4, in Base Case, there are 24 black dots under N/NE-Wind and 29 black dots under S/SE-Wind; in Variant I, there are 21 and 23 black dots under N/NE-Wind and S/SE-Wind; in Variant II, there are 21 and 39 black dots under N/NE-Wind and S/SE-Wind accordingly. Therefore, the comfortable time percentage in a year for Base Case, Variant I

and II are 37.10%, 30.67% and 42.72%. This means that the comfortable time in a year is increased by 5.62% by adding atrium, and 12.04% by adding openings in this building. The detailed calculation is shown in Table 5.

The velocity magnitudes at P-a for all 3 cases and four wind scenarios are shown in Figure 6. From Figure 6, we can see that, the velocity magnitude increases and then decreases within a level, which forms a parabola pattern. For all three cases and 4 wind directions, the velocity magnitude from level 2 to level 6 is the lowest compared with the other levels. For N-Wind, there is a big difference in velocity magnitude between Variant II and Base Case; for other wind directions, the velocity magnitude of Base Case and Variant II is very similar. Variant II has higher velocity magnitude than Variant I in almost all scenarios, except S/SE-Wind Level 1.

CONCLUSION

In this research effort, we have investigated the natural ventilation performance towards optimal freeform architecture design. We demonstrated the process and generated a set of CFD models on the basis of wind directions, tropical climate and building heights. The following main conclusions are drawn from this study: in such a freeform architecture design, 1) the volume-weighted average velocity of atrium is increased by 4.4% by adding atrium; 2) the percentage of comfortable time calculated based on air velocity on an annual basis is increased by 5.61% by adding the atrium; 3) the volume-weighted average velocity of atrium is increased by 7.91% by adding openings and using naturally ventilated staircases; 4) the percentage of comfortable time calculated based on the air velocity on annual basis is increased by 12.04% by adding openings and using naturally ventilated staircases. In the future, long-term monitored data collection and analysis will be further investigated. Further thermal comfort analysis will be carried out.

ACKNOWLEDGMENTS

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Table 4
Statistics of wind directions where human comfort based on air speed is matched.

		P-a				P-b				P-c				P-d			
		N	NE	S	SE	N	NE	S	SE	N	NE	S	SE	N	NE	S	SE
Base	L1	●		●		●	●		●	●		●	●				
	L2	●			●												
	L3	●															●
	L4	●	●														●
	L5	●			●												
	L6				●		●		●								
	L7				●		●		●		●	●	●			●	●
	L8	●	●	●	●	●		●	●	●	●		●	●	●		●
	L9	●	●	●	●	●		●	●	●		●	●	●	●		●
Variant I	L1	●		●	●	●	●		●		●		●	●			
	L2																
	L3																
	L4																
	L5																
	L6																
	L7				●		●		●		●	●	●			●	●
	L8	●	●			●	●	●	●	●	●	●	●	●	●	●	●
	L9	●			●	●		●	●	●	●	●	●	●	●	●	●
Variant II	L1		●	●	●			●	●	●			●				
	L2				●				●								
	L3						●										●
	L4						●										●
	L5		●		●								●				●
	L6		●		●		●		●								●
	L7		●	●	●			●	●		●	●	●		●	●	●
	L8		●	●	●	●		●	●	●	●	●	●		●	●	●
	L9	●	●	●	●	●		●	●	●	●	●	●		●	●	●

Table 5
Comfortable time percentage calculation in a year based on air velocity at 4 points.

Wind Directions	**Parameters**	**Base Case**	**Variant I**	**Variant II**
N/ NE	No. of black dots	24	21	21
	Possibility of black dots (%)	33.33	29.17	29.17
	Possibility N/NE in a year (%)	45.8		
S/ SE	No. of black dots	29	23	39
	Possibility of black dots (%)	40.28	31.94	54.17
	Possibility of S/SE in a year (%)	54.2		
Comfortable time percentage in a year (%)		37.10	30.67	42.72

THE EFFECTS OF FENESTRATION SYSTEMS ON OCCUPANT THERMAL AND VISUAL COMFORT IN THE TROPICS

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ABSTRACT

Thermal and visual discomfort are the two main causes why occupants of buildings in Singapore often close their window blinds - at the expense of natural daylight and visual contact with the outdoor environment. Window blinds modify the thermal and optical properties of a fenestration system and often adversely affect the façade energy efficiency, particularly the daylight utilization.

Parametric simulation analyses were conducted to study the effects of six typical fenestration systems on the thermal and visual comfort of occupants in the tropical climate conditions in Singapore, for the four cardinal façade directions.

The results show that both thermal comfort and visual comfort are strongly correlated to solar radiation. Addressing the discomfort issues for the east/west-oriented facades turned out to be the most challenging part. It was also found that the time fraction with thermal and visual discomfort is small when using glasses with low solar and visible light transmittance.

INTRODUCTION

Building facades with large window-to-wall ratio (WWR) are preferred nowadays, for reasons such as improved daylight utilisation, outlook and building image (Boyce et al., 2003). In contrast to that, a significant percentage of office workers sitting next to windows prefer partially or fully closing their window blinds, for reasons such as glare, thermal discomfort or privacy (Rea, 1984; Maniccia et al., 1999). In fact, occupants are willing to give up natural daylight and outlook, when it causes thermal and/or visual discomfort (Boyce et al., 2003).

In the development of energy-efficient façade and fenestration technologies, the comfort of the occupants should not be compromised. If the thermal and visual comfort requirements are not considered in the design stage, the fenestration system may not operate according to the intended design. The unforeseen use of window blinds, for example, affects the overall indoor environmental conditions and building energy efficiency adversely. A study conducted in a government office building in Malaysia (Lim et al., 2012) revealed that introducing light shelves improved the daylight uniformity, but actually worsen the glare problem. Internal shading devices such as blinds were necessary to control the direct sunlight patches to avoid the glare problem. The window, light shelves and blinds therefore have to be considered as an integral system.

It is hence important to understand the effects of typical fenestration systems on the thermal and visual comfort of the occupants in the tropics. However, limited studies have been reported in the literature. Chaiyapinunt et al. (2005), Singh et al. (2008), and Hwang and Shu (2011) studied the impact of different glazing systems on human thermal comfort based on climate conditions in Thailand, India and Taiwan, respectively. All of them highlighted the importance of solar radiation on thermal comfort. For visual comfort studies, Lim et al. (2012) and Sherif et al. (2012) studied the visual comfort performance of complex fenestration systems in Malaysia and Egypt, respectively. Both studies reported that shading devices (blinds or solar screens) are able to reduce daylight glare effectively.

In the present study, parametric numerical simulations were conducted to study the effects of six common fenestration systems in Singapore on the thermal and visual comfort of the occupants.

SIMULATION METHODOLOGY

A reference room was used as a representative unit of a typical office building in Singapore. The configuration of the reference room was fixed, except for its façade orientation and fenestration type, which were changed in the parametric analyses.

The thermal comfort level was characterized by the predicted mean vote (PMV) index (ISO, 2005), with modifications considering the impact of diffuse and direct solar radiation (La Gennusa et al., 2007). The visual comfort level was characterized by the daylight glare probability (DGP) index (Wienold and Christoffersen, 2006).

Description of the reference room

The geometry of the reference room is shown in Figure 1. The room was 3 m wide and 4 m deep, with

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a ceiling height of 2.5 m. The room is a representative office cell of a high-rise office building. Its floor was 12 m above the ground. The window width was the same as the room width. Its height was 1.2 m, and window bottom line was 1 m above the floor. This is a typical configuration for curtain wall façades. The window-to-wall ratio (WWR) was 48%.

For the reference room, all internal walls (i.e. the three walls without windows), floor and ceiling were assumed as adiabatic. The external wall (i.e. the front wall with the window) was exposed to external sun and wind.

For simplicity, a lightweight wall construction with thermal insulation was assumed for all walls, the floor and the ceiling. The U-value was 0.4 W/ (m^2K) for all wall constructions. The window was assumed to consist of glass only and the window frame effects were ignored. This simplification was valid as detailed energy calculation was not the objective of the simulation here.

Typical values of solar absorptance of 0.6 and emissivity of 0.9 were assumed for all opaque building elements. For daylight analysis, visible light reflectance (VLR) was assumed as 0.6 for walls, 0.7 for the ceiling, and 0.3 for the floor, respectively.

For the usage profile, it was assumed that the office was occupied during weekdays from 9:00h to 18:00h all year long, and that the space was air-conditioned from 8:00h to 19:00h during weekdays by an ideal air-conditioning system. The room air set-point temperature was assumed to be 24°C during office hours. The heat addition by people, electrical light and electrical equipment were defined as 126 W, 60W, and 250 W, respectively, and during office hours only.

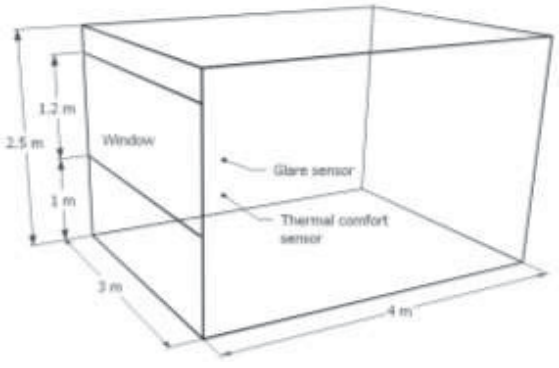


Figure 1: Schematics of the reference room for the thermal and visual comfort analysis

Thermal comfort modelling

The PMV model described in ISO 7730 (ISO, 2005) has been widely adopted for the evaluation of the thermal comfort level. The main environmental parameters relating to thermal comfort are air temperature, mean radiant temperature (MRT), relative humidity and air velocity. In the ISO 7730 thermal comfort model, the MRT calculation considers the effect of the long-wave heat exchange between the human body and the window/wall surfaces, but excludes short-wave (solar) radiation that penetrates through the window glass and reaches on the human body. Recent studies conducted by Chaiyapinunt et al. (2005), Singh et al. (2008), and Hwang and Shu (2011) confirmed that large discrepancies could result if the influence of direct solar radiation on the human thermal comfort is ignored.

In order to take into account such influence of solar radiation on thermal comfort, the model developed by La Gennusa et al. (2007) was used. The modified MRT (or irradiated MRT), MRT_{irr} , with considerations of long wave radiation, diffuse solar radiation and direct solar radiation can be expressed as:

$$MRT_{irr}^4 = MRT_{ur}^4 + \Delta MRT_{diff}^4 + \Delta MRT_{dir}^4, \qquad (1)$$

where MRT_{ur} is the long-wave radiation only MRT (or un-irradiated MRT, as defined in ISO 7730), ΔMRT_{diff} is the MRT increment due to transmitted diffuse solar radiation, and ΔMRT_{dir} is the MRT increment due to transmitted direct solar radiation. EnergyPlus software (V7.1, EnergyPlus website, 2013) was used in the thermal performance simulations (according to the ISO 7730 model). The hourly variables related to MRT_{ur} , ΔMRT_{diff} , and ΔMRT_{dir} were then exported from EnergyPlus and an external program was developed to calculate MRT and PMV, according to La Gennusa et al. (2007) and ISO 7730 (2005).

The thermal comfort calculations were performed in terms of a thermal comfort sensor shown in Figure 1. The thermal comfort sensor was located 1 m away from the window, 0.8 m above the floor and on the centre plane in the room width direction (i.e. 1.5 m to both sidewalls adjacent to the window). The occupant was assumed at a sitting position, facing one of the sidewalls. The thermal comfort sensor position was representative of the chest position of a seated adult.

The other relevant parameters used were clothing insulation: 0.57 clo (shirt with short sleeves); metabolic rate: 1.2 met (office sedentary activity); air velocity: 0.15 m/s; human body solar absorptance: 0.6. The form factors between the human body and the room surfaces were calculated with the simplified algorithm developed by Rizzo et al. (1991).

Visual comfort modelling

Various glare indices have been developed to characterize the visual comfort level in the daylit spaces. The daylight glare index (DGI, Hopkinson, 1972) and the daylight glare probability (DGP, Wienold and Christoffersen, 2006) are often used for visual comfort assessment under daylight conditions (da Silva et al., 2012). Various studies suggested that DGP performs better than DGI (Wienold and Christoffersen, 2006; Van Den Wymelenberg et al., 2010; Jakubiec and Reinhart, 2012), especially when direct sunlight is presented. Furthermore, DGP is able to predict glare in exceedingly bright scenes, whereas DGI is purely based on the contrast of brightness (Jakubiec and Reinhart, 2012).

The EnergyPlus software calculates DGI, but it is not able to calculate DGP. The DAYSIM software (DAYSIM website, 2013) was therefore used for annual daylighting analysis. DAYSIM is based on the Radiance backward ray-tracing software (Radiance website, 2013). The enhanced simplified DGP, developed by Wienold (2009) is used by DAYSIM for glare prediction.

As shown in Figure 1, the glare sensor is directly above the thermal comfort position, with a height of 1.2 m from the floor. The glare sensor position is representative of the eye position of a seated adult. Similar to the thermal comfort modeling, the occupant was assumed facing one of the sidewalls (the window was on his left side).

Table 1: Properties of the 4 different glazing materials under investigation

No	1	2	3	4
Short name	Single clear	Single tinted	Single low-e	DGU
ST	0.889	0.179	0.265	0.262
SR, front	0.078	0.045	0.276	0.492
SR, back	0.078	0.045	0.247	0.530
VLT	0.912	0.345	0.552	0.662
VLR, front	0.082	0.049	0.088	0.113
VLR, back	0.082	0.049	0.109	0.129
U-value	5.28	5.25	2.92	1.57
SHGC	0.898	0.424	0.360	0.284

ST: solar transmittance; SR: solar reflectance; VLT: visible light transmittance; VLR: visible light reflectance; U-value: thermal transmittance (summer condition, unit: [W/(m^{2}K]); SHGC: solar heat gain coefficient; front: the outdoor side of a glazing system; back: the indoor side of a glazing

RESULTS AND DISCUSSION

For the reference room described above, numerical experiments were conducted for four types of typical window glazing materials to understand their effects on thermal and visual comfort. As an externally fixed horizontal overhang shading is one of the most common shading types in Singapore, the effects of horizontal overhang, combined with two glazing systems, were also studied. In total, 6 fenestration

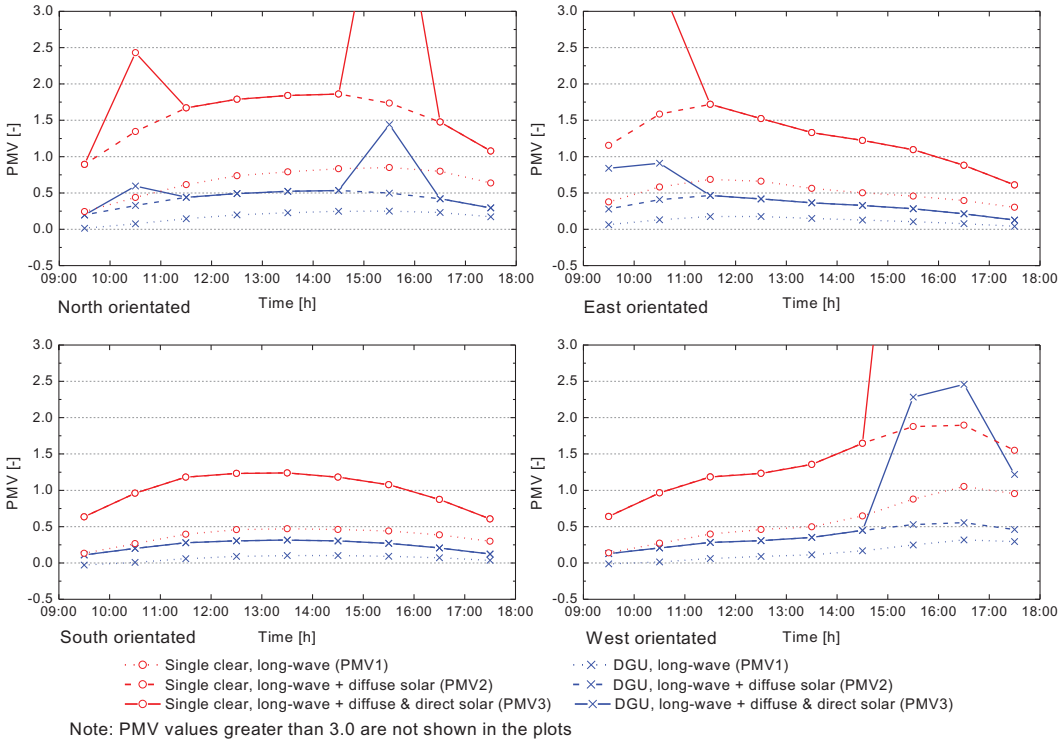


Figure 2: Hourly Predicted Mean Vote (PMV) simulation results for different orientations and six different glazing types (data for June 21 in Singapore)

systems were investigated.

The four glazing materials used were: 1) single clear glass (referred to as "single clear" in the following), 2) single tinted glass ("single tinted"), 3) single low-emissivity, "low-e" glass ("single low-e"); and 4) low-e double glazing unit ("DGU"). Table 1 lists the solar and luminous properties of the glazing materials. The four glazing materials were selected as they are commonly used in buildings in Singapore. Single clear and tinted glasses are typically found in existing buildings, while new developments favor low-e glasses, particularly low-e DGUs, due to their significantly better thermal insulation and solar heat gain control performance. For each of the glass types, simulations were performed for the four cardinal directions.

For simplicity, it was assumed that the horizontal overhang is made of a flat plate, directly attached to the top edge of the window, protruding 0.5 m from the façade. To reduce the total number of simulations, the horizontal overhang was only combined with the single clear glass and the low-e DGU glass for the numerical analysis.

Thermal comfort analysis

Figure 2 shows the hourly PMV values calculated for the two glazing types, single clear glass and DGU, representing the worst and the best glazing types in terms of thermal performance, respectively, for June 21. Three types of PMVs are presented, i.e. PMV based only on the long-wave radiation mean radiant temperature, MRT (hereafter referred to as PMV1), PMV based on long-wave radiation and transmitted diffuse solar radiation MRT (hereafter referred to as PMV2), and PMV based on long-wave radiation and transmittance diffuse and direct solar radiation MRT (hereafter referred to as PMV3). Satisfactory thermal comfort levels are defined as -0.5 < PMV < +0.5, according to category B thermal environment, ISO 7730.

Though ideal air-conditioning system was assumed and room air temperature is kept constant at 24°C during office hours, the PMV1 still varied due to indoor surface temperature variations. It was evident that, for the west-oriented façade, the PMV1 was higher in the afternoon time. For all façade orientations, the PMV1 calculated for the façade with single clear glass was higher than that with DGU. The window with single clear glass has a higher solar transmittance and it admits more solar radiation. The transmitted solar radiation is partially absorbed by opaque surfaces in the room and in turn causes the increase of the long-wave radiation MRT. This mechanism is different from the usual assumption that windows affect human thermal comfort by its own surface temperature rise only (e.g. Chaiyapinunt et al., 2005). The present finding suggests that it may not be appropriate to use a uniform cooling setpoint

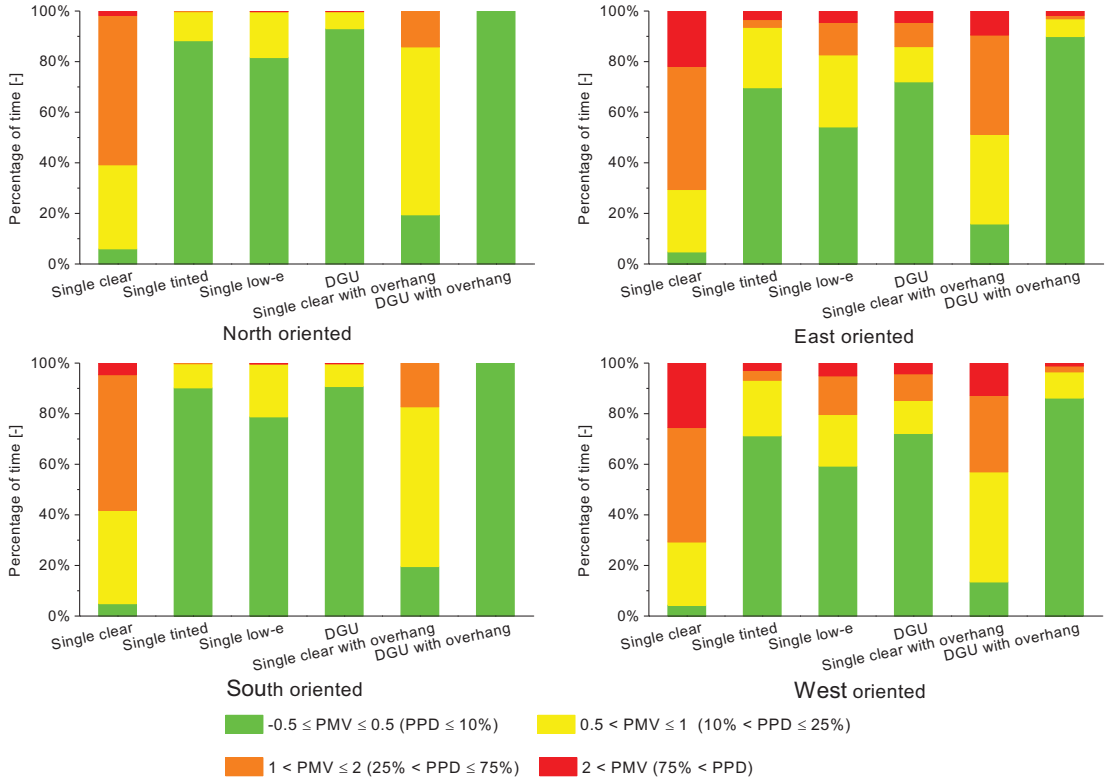


Figure 3: Annual time percentage distribution of four Predicted Mean Vote classifications based on long-wave radiation, transmittance diffuse and direct solar radiation mean radiant temperature (MRT), here called "PMV3" value categories as a function of orientation for six different glazing types

for rooms at the building core and the perimeters.

For all façade orientations, the PMV2 was higher than the corresponding PMV1. The increment was more significant for the cases with single clear glass, due to its higher solar transmittance. For the single clear glass cases, the PMV2 was greater than +1 for a certain period of the day for all façade orientations. This falls into the "slightly warm" category of the thermal sensation scale, as defined in ISO 7730.

The PMV3 results are dependent on the geometric relationship between the sun, the window and the thermal comfort sensor. If the sensor point was not directly irradiated by the sun, PMV3 was equal to PMV2, i.e. the contribution of direct solar radiation to thermal comfort is zero. If the point was directly irradiated by the sun, PMV3 increased dramatically. In certain scenarios, PMV3 was even greater than +3, i.e. the thermal environment was in the "hot" scale of ISO 7730.

PMV3 is the more realistic metric for thermal comfort evaluation. For the results presented in Figure 2, only the south-orientated façade with low-e DGU provided satisfactory thermal comfort level throughout office hours.

Figure 3 shows the annual time percentage distribution of PMV3 during office hours. Four PMV3 classifications are defined. They are also known as Predicted Percentage Dissatisfied occupants (PPD, ISO, 2005).

It is obvious that the single clear glass performed the worst. The single tinted glass was in fact slightly better than DGU in terms of thermal comfort regulation. The findings are contradictory to the usual assumption that tinted glass has higher surface temperature due to its high solar absorptance and its higher surface temperature in turn causes thermal discomfort problems (e.g. windows for high performance commercial buildings website, 2013). In the present study, the distance between the thermal comfort sensor and the window was 1 m and the form factor between the human and the window was 0.09.

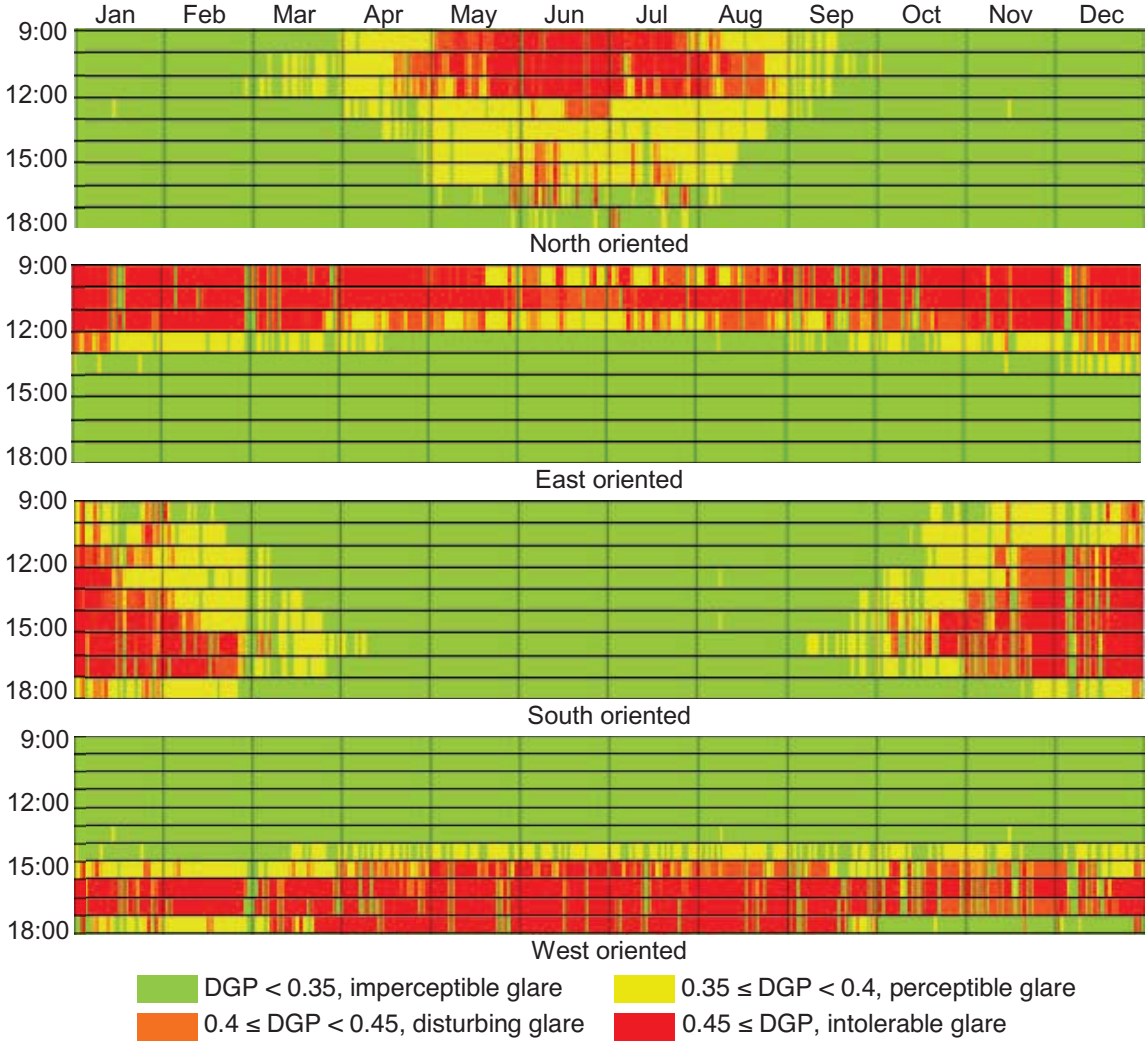


Figure 4: Annual daylight glare probability (DGP) distribution for the single clear glass as a factor of orientation and time of the day/year

The solar transmittance of the glazing material, rather than the solar absorptance, is the controlling factor of the thermal comfort performance. Higher solar transmittance values of the glazing material caused higher indoor opaque surface temperature, and more transmitted diffuse and direct solar radiation.

For the simple horizontal overhang evaluated, it was fairly effective when it was installed with the DGU glass. In fact, for the south- and north-oriented facades with DGU and overhang, PPD was less than 10% for 100% of the time. Though there was also significant improvement when the overhang was installed with the single clear glass, the overall performance was not satisfactory, due to its high solar transmittance. The east- and west-oriented facades have more severe thermal discomfort problems for all glazing types. The overhang did not perform well for these two orientations. It is obvious that more effective shading devices (e.g. blinds) are required for the east and west orientations.

For all glazing systems with low solar transmittance (i.e. excluding the single clear glass), the time fraction with PMV greater than +1 was in general less than 20% for the east/west-oriented facades, and less than 1% for the north/south-oriented facades. The time fraction with thermal discomfort was therefore relatively small.

Visual comfort analysis

Figure 4 shows the annual daylight glare probability (DGP) calculation results for the single clear glass. It was the worst-case scenario amongst the four glazing types studied, due to the largest visible light transmittance of the materials under investigation. According to the DGP definition, the glare level is considered to be "imperceptible" (DGP < 0.35), "perceptible" (0.35 ≤ DGP < 0.4), "disturbing" (0.4 ≤ DGP < 0.45), or "intolerable" (DGP ≥ 0.45), as mentioned in the figure.

It is evident that the glare level is strongly dependent on the sun position and the façade orientation. For the north-oriented façade, there was disturbing or intolerable glare between April and August, mainly in the morning time (as the glare sensor faces east for the north-oriented façade case). In the months of October to February, the glare level was in general imperceptible. This observation suggests that direct sun light is the controlling factor of the glare perceived by the occupants. The south-oriented façade exhibited a similar glare probability pattern, except that the high glare level season was between October and February.

Due to the low solar altitude angle in the morning (for the east-oriented façade) or in the afternoon (for the west-oriented façade), disturbing or intolerable glare was experienced throughout the whole year for the east/west-oriented façades. Though the number of calendar days with high glare level for the east- and west-oriented facades were more, the time fraction with high glare levels was still limited. The glare level was in general below the perceptible glare level

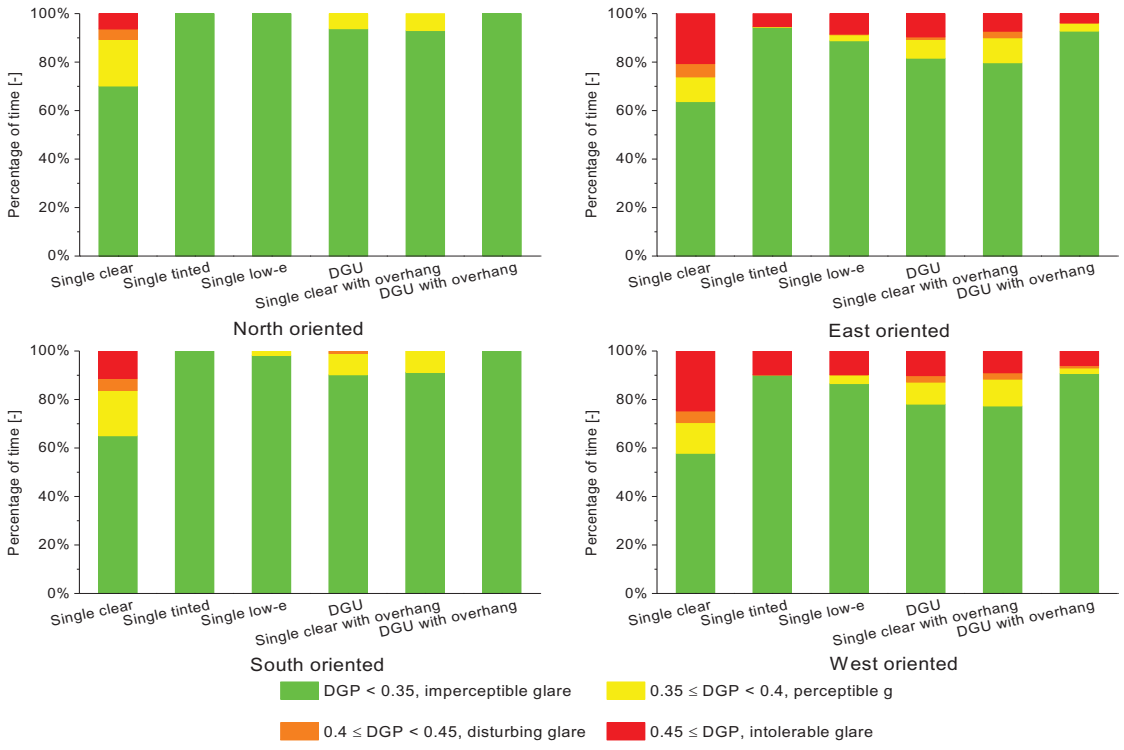


Figure 5: Annual time percentage distribution of daylight glare probability (DGP) as a function of orientation for six different glazing types

after 2pm for the east-oriented façade or before 2pm for the west-orientated façade.

Figure 5 shows the annual time percentage distribution of DGP during office hours. The glare level scales used in Figure 4 are shown. For the north- and south-oriented façades, none of the glass types, except the single clear glass, had noticeable glare problems. It suggests that for these two façade orientations, using glass materials with lower visible light transmittance was an effective glare reduction measure. The simple horizontal overhang shading worked well for these two orientations. Disturbing and intolerable glare was eliminated even for the case with single clear glass and overhang.

It is however, more challenging to reduce the glare level for the east- and west-oriented façades. For the tinted glass with low visible light transmittance (0.345), DGP was above 0.45 (intolerable glare) for 5.3% of the total office hours for the east-oriented façade, and 9.7% for the west-oriented façade, respectively. Due to other considerations in façade design, including daylight utilization, visual contact to the outdoor environment and color appearance of the façade, it is not practical to eliminate disturbing and intolerable glare by lowering the visible light transmittance of the glass material alone. The horizontal overhang was able to reduce the time fraction with high glare level, but it was not able to eliminate intolerable glare for the two glass types evaluated. On the other hand, the time fraction with intolerable glare was in general less than 10% for all scenarios, except the case with un-shaded single clear glass.

CONCLUSIONS

Parametric simulation analyses were performed to understand the effects of six typical fenestration systems on the thermal and visual comfort of occupants in Singapore's tropical climate.

Proper performance indices are required for accurate prediction of thermal and visual comfort. The thermal comfort calculation model defined in the ISO 7730 standard does not consider the contribution of diffuse and direct solar radiation to human comfort and under-estimates the thermal discomfort level noticeably.

The results showed that both thermal comfort and visual comfort are strongly correlated to solar radiation, both diffuse and direct. Direct solar radiation can cause enormous increase of thermal and visual discomfort levels.

For the thermal comfort, solar transmittance of the glass materials, rather than solar absorptance, was observed to be the main controlling parameter. For glasses with high solar transmittance, the surface mean radiant temperature (MRT) of the room surfaces was higher and in turn caused thermal discomfort.

For visual comfort, visible light transmittance was observed to be the main controlling parameter. Using glass materials with low visible light transmittance can effectively reduce or eliminate glare for the north/south-oriented facades. Similarly, for these two orientations, simple horizontal overhangs worked well for both thermal and visual discomfort reduction.

It is more challenging to reduce the thermal and visual discomfort for the east/west-orientated facades. Fortunately, it could be shown that the time fraction with high levels of thermal discomfort and visual discomfort is in general small.

For energy-efficient façade development, it is not necessary to cover the east/west oriented windows with shading devices for the entire occupied hours. Active façade systems, including switchable glazing and motorized blinds, could be effective alternatives for these two orientations.

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AUTOMATIC CARBON TOOL FOR MULTI-STAKEHOLDER CARBON PERSPECTIVES

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ABSTRACT

Carbon computational tools are increasingly used by building professionals to quantify the carbon impact of buildings. While contemporary carbon tools can ease carbon quantification process, the use of it is known to be restricted to post-design building level evaluation and do not support multi-stakeholder carbon perspectives across design process. The need for extensive input data, lack of dependable localized carbon data, lack of scalability, and interoperability issues makes carbon computation tedious, time-consuming, and difficult and therefore impedes the usability and integration of carbon tools in design process.

Keeping with Singapore's national carbon agenda to achieve carbon reduction by 11% below business-as-usual levels by 2020, this paper elaborates on the development of a new carbon tool designed to work seamlessly with existing modelling software without any disruption or deviation from current work processes, and supports and facilitates multi-stakeholders decision-making process. The new carbon tool builds up a supporting technology with locally-adapted databases, calculation methodologies, and computational techniques (focusing on automation, scalability, interoperability) to satisfy carbon quantification needs and ease previously difficult carbon computation processes, thereby enhancing carbon decision-making capabilities of stakeholders without enforcing the need to invest in time and effort to learn carbon computation methods and software technicalities.

Existing concepts of carbon computation, building information modelling, with tacit knowledge of local work practices required for the various design disciplines, were used to formulate a consistent and dependable carbon model. Fundamental technologies and methodologies encapsulating the mentioned features forms the basic software framework, allowing the new carbon tool to be used for design-support activities and allowing stakeholders to maintain a carbon perspective throughout the planning and design process. The basic technologies and capabilities of the carbon tool shall be demonstrated by means of a use-case scenario.

INTRODUCTION

Carbon emission and its effects on global warming and climate change have increasingly garnered global interest in recent years. Conclusive of the 2009 Copenhagen Accord, many are advocating for immediate carbon mitigation policies and regulations. In Singapore, the government has expressed interest and commitment to reduce national carbon emissions by 7-11% from business-as-usual levels by 2020. Given that buildings account for 20% of annual carbon emission, achieving successful carbon reduction on this front can have significant impact on national carbon levels. Having an effective management of building carbon emission though, can be a large-scale effort and entails the direct involvement of various stakeholders ranging from government agencies, developers, urban planners, to architects. It is therefore of national importance that building professionals from these diverse disciplines are equipped with the tools and skillsets to efficiently manage carbon emission of buildings. This however does not come as an easy feat for building professionals in Singapore. The lack of local policies or standards makes it difficult for building professionals to embark on carbon computation. Many lack operative knowledge on the requirements, technicalities, and methods to perform carbon computation. Even if much time and effort was spent on building such expertise, the primitive nature of existing carbon tools as merely a post-design building evaluative carbon computational tool limits the usefulness of carbon computation in any planning or design activity. These tools are not scalable across design process, and do not consider the technical differences and computational needs of varying stakeholders. For each stakeholder to perform carbon computation at different stages of design will mean having to simultaneously deal with varying modelling, simulation, and computational techniques; a task which requires experience and tacit knowledge. The key challenge in successfully implementing carbon computation in Singapore's building industry is thus at the operational level for agencies and building industry to have a technology that is dependable, eases carbon computation, considers the carbon perspective of various stakeholders, and supports planning and design activities throughout design process.

MULTI-STAKEHOLDER CARBON PERSPECTIVES

Building up a comprehensive carbon model requires the identification and differentiation of various stakeholders' carbon objectives, requirements, and targets, as well as an understanding of their work practices, planning and design activities. For every building project, each stakeholder brings in a unique carbon perspective that drives the direction of design

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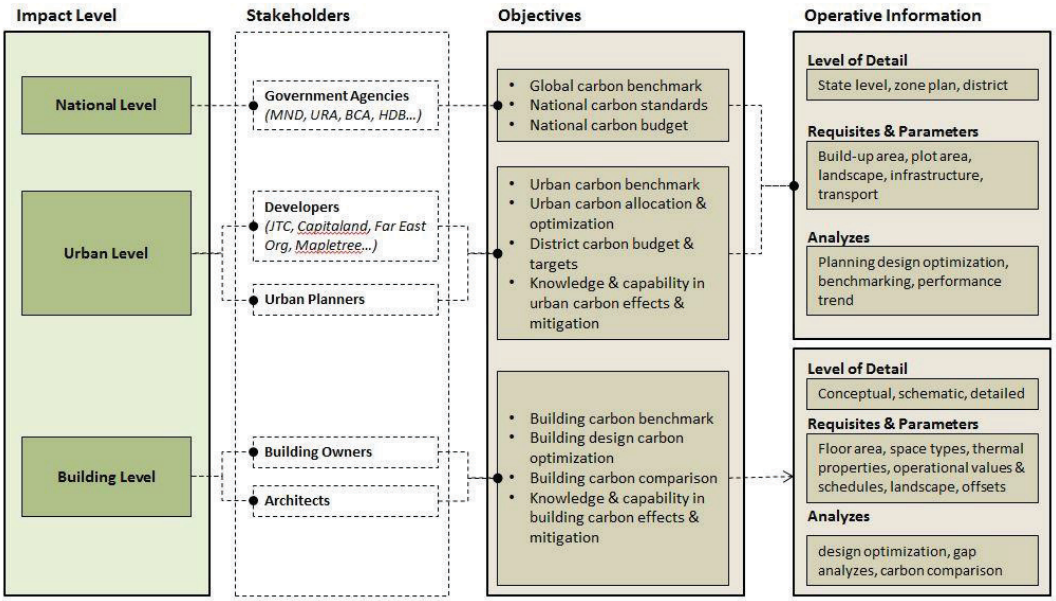


Figure 1 Multi-stakeholder carbon objectives & required operative information

process and the final outcome of the product. By understanding the different carbon perspectives of various stakeholders, their specific needs and objectives can be translated into operative information, where appropriate technologies can be identified and developed to support better carbon computation needs in the new carbon tool (Fig 1).

Government agencies (URA, BCA and HDB) that have direct influence over the planning and development of buildings in Singapore are interested in guarding the national interest towards achieving the carbon agenda, being able to formulate carbon mandates, and alter policies and building regulations to incentivise and encourage carbon awareness. The perceptive usefulness of a carbon tool for the agencies therefore comes from the ability to manage carbon at all levels of detail, ranging from large-scale urban planning, district and precinct planning, to building design, with particular emphasis on being able to draw upon gained knowledge for carbon road-mapping and policy making. Such carbon objective can be translated into implementable technological features that not only allow carbon computation, but are also embedded with relevant analytical methods to postulate carbon trends based on baseline scenarios and perform carbon benchmarking based on national carbon targets.

Developers and urban planners on the other hand are interested in facilitating carbon management of buildings and other infrastructure within an allocated urban precinct, with specific objectives to keep in-line with national carbon agenda and to benefit from carbon savings in their development. Their form of carbon analysis goes beyond segmented investigation of carbon emission in individual buildings, but instead looks at the urban infrastructure as a whole entity. This includes having a carbon tool that accounts for build-up area, infrastructure, landscape, and transport, with supporting capabilities to explore various planning configurations and perform gap analyzes for systematic identification of carbon performance and potential carbon mitigation strategies.

Lastly, the carbon perspective of architects and designers involves carbon computation on a building level, with specific objective to deliver high performance integrated building design through gained knowledge pertaining to low-carbon building design and optimization. Their approach to carbon analysis emphasizes on the ability to perform relational analyzes between design variations, materials, and daily operations to highlight potential gaps in carbon performance and explore pertinent mitigation strategies. Useful carbon analysis in this discipline is thus one that enhances decision-making and supports performance-based design practices.

TECHNICAL SHORTFALLS

Several known challenges arise from the list of requirements needed to enable multi-stakeholder carbon computation. At different design stages (conceptual, schematic, detailed), the presence of varying levels-of-detail (LOD) makes it difficult for a single carbon tool to be consistently used across design stages. The availability of information invariably determines the technical approaches used to calculate carbon. Given that each stakeholder functions at different design stages, the type of software, simulation, and computation methods will differ. This meant having to learn new technical approaches for modelling, simulation, and analysis in

order to perform carbon computation. The carbon tools are therefore not scalable and the operative use of the tool can be additionally taxing on user.

Existing carbon tools are also not interoperable between domains. Most existing modelling software does not support the sharing of building information with other performance evaluation tools (Wong, 2000, Bazjanac, 1997, Papamichael, 1997). Software-based carbon calculators that are developed for specific software may not be interoperable with the other diverse set of modelling software used in industry practices. Such lack of interoperability between modelling, simulation, and evaluation tools meant having to simultaneously work on different software platforms, alluding to the need to invest time and cost to learn new approaches as described above.

Even when dealing with each software platform, the logistical input of information for computation and simulation can be manual and repetitive. The semantic and syntactical differences between modelling and simulation tools often result in conflicting and missing information. To perform carbon calculation, users are required to manually transfer and translate geometrical models into different software platform and repopulate missing information; a process that is noted by researches (Mahdavi, 1993, Lam, 1999, and Wong, 2000) to be time consuming, high in redundancies, and error-prone. This meant disruptions in the design workflow and does not promote productivity nor improve efficiency of current practices.

Apart from the existing limitations in technical capabilities, there is also a lack of locally adaptable carbon database which Singapore can use. Most carbon data originates from international sources (US, UK, New Zealand) and are not directly applicable to Singapore's context. Using these figures will risk under-estimating or over-estimating carbon emission, resulting in a less dependable carbon evaluation(Fig 2). Researches (Padgett, 2008, Bottrill, 2007, Pablo, 2009) noted significant inaccuracies due to varying input methods, calculation methods, and carbon database, making it difficult to ascertain the accuracy and reasonableness of carbon results. The use of such carbon tool therefore impedes meaningful and applicable knowledge to stakeholders.

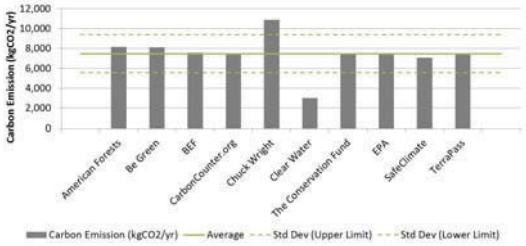


Figure 2 Disparate tools, different carbon results

TECHNICAL ADVANCES

The development of the new carbon tool is thus heavily based on addressing the challenge of 1) improving computational capabilities and increasing productivity, 2) achieving scalability across disciplines and design stages, 3) formulating a dependable carbon database and calculation method, and 4) ensuring developed tool will remain applicable and relevant to the larger audience and supports extensibility. Through close examination of local industry practices and policy processes by various stakeholders, technical innovations in the following computational fronts are developed.

- Localized carbon method & database
- Automation & scalability of carbon model
- Interoperability with prevalent design and simulation tools

Outcome of these technical innovations will be a new carbon tool that is immediately implementable, highly integrative, and non-disruptive. The new carbon tool will facilitate enhanced quantification capabilities of building industry, provides ease of computation, and supports multi-stakeholder decision making across project stages through the effective management of carbon perspective in planning and design of Singapore industrial developments.

LOCALIZED CARBON METHOD & DATABASE

The new carbon tool focuses squarely on first establishing the appropriate carbon methods and databases that are suitable for Singapore's context and supports the implementation of the fundamental technology involved for carbon computation. All carbon computation methods used in the new carbon tool are founded upon well-established international standards, where embodied and operational phases are identified as the two main contributors of carbon emissions in building (UNEP, 2010, WRI, 2004, IEA, 2010). Organizational carbon, being insignificant and difficult to establish, is excluded from the new carbon tool. These findings are found to be largely consistent and applicable to Singapore's context (Huang, 2012).

Carbon emission factors that make up the set of carbon assumptions primarily draws upon available international carbon standards. While carbon factors for operational electricity are straightforward and easily obtainable, sourcing for appropriate embodied carbon emission factors for Singapore's context can be difficult. Bulk of existing embodied carbon factors are founded upon research done in the States, United Kingdom, and New Zealand. To reasonably apply international embodied emission factors in Singapore, the default embodied calculation equation appends the estimated carbon required to ship the materials from the various source locations to

Singapore. A constant shipping emission factor, obtained from DEFRA is used to multiply with distance required to transport materials from each country to obtain total transportation carbon emission. The summation of material emission factor and transport emission factor will give the total embodied carbon emission (Fig 3). In doing so, a reasonable carbon database can be depended upon for carbon computation, while better and more localized carbon emission factors can be derived from local research and be updated in the carbon database in future.

Embodied Carbon=Mass x [Material emission factor + (Distance X Cargo Emission Factor)]

Name	Material emission factor	Shipping to Singapore				Total emission factor
		Country	Distance	DEFRA General cargo emisison factor	Total shipping	
	kgCO2/kg		km	kgCO2e/tonne-km	kgCO2e/kg	kgCO2/kg
Aluminium, anodized	9.359	NZ	10,911	0.015	0.164	9.523
Carpet, synthetic	3.89	UK	8,462	0.015	0.127	4.017
Cement, average	0.994	NZ	10,911	0.015	0.164	1.158
Cement, mortar	0.213	UK	8,462	0.015	0.127	0.340
Ceramic tile	0.59	UK	8,462	0.015	0.127	0.717
Concrete block	0.103	NZ	10,911	0.015	0.164	0.267
Concrete, pre-cast	0.214	NZ	10,911	0.015	0.164	0.378
Concrete in-situ	0.159	UK	8,462	0.015	0.127	0.286
Concrete, ready-mix 30MPa	0.159	NZ	10,911	0.015	0.164	0.323
Insulation Rockwool	1.05	UK	8,462	0.015	0.127	1.177
Flooring, vinyl	2.29	UK	8,462	0.015	0.127	2.417
Glass, laminated	1.743	NZ	10,911	0.015	0.164	1.907
Gypsum, plasterboard	0.421	NZ	10,911	0.015	0.164	0.585
Paint	3.56	UK	8,462	0.015	0.127	3.687
Steel, structural	1.242	NZ	10,911	0.015	0.164	1.406
Steel, reinforced, sections	0.352	NZ	10,911	0.015	0.164	0.516
Steel, rebar	1.71	UK	8,462	0.015	0.127	1.837
Timber, plywood	75.865	AUS	4,433	0.015	0.066	75.931

Figure 3 Locally adapted material emission factors

AUTOMATION & SCALABILITY

Without having to learn new software approaches and technicalities, the development of the new carbon tool leverages on existing building information modelling (BIM) and simulation technologies. Keeping in line with BCA's advocacy for BIM as a standard building submission platform, the new carbon tool is designed to integrate well with local widely adopted design modelling platform - Revit Architecture. Users only need to conform to typical modelling conventions in Revit where design models at varying levels of abstraction (according to design stages) are architecturally represented by different modelling entities in Revit. The tool will automatically translate all pertinent building information into usable data for energy simulation and carbon computation, and present instantaneous carbon analysis (Fig 4). Such enabling technology lies in the automation of information transfer between different software domains, and the automation of all logistical tasks required for carbon computation.

Automation of information transfer

The basis of automation depends on a complete and well-formed Shared Object Model (SOM), which

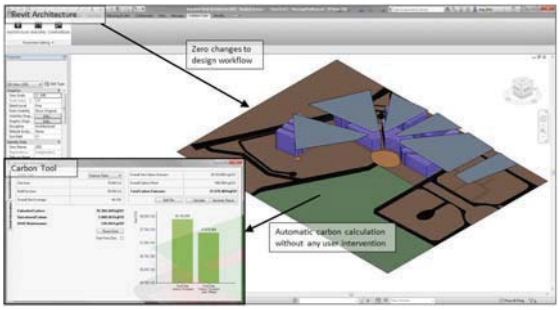


Figure 4 Instantaneous result at a click of a button

functions like a general BIM devoid of domain specificities. The SOM functions like a mapper, facilitating information transfer between domain models EnergyPlus, Revit, and XML database. An example of such application is the translation of user-defined materials within Revit to the equivalent material entities to be specified in EnergyPlus, and carbon database (Fig 5). For every material specified within the Revit BIM model, a support module within the SOM formulates association, automatically translates, and performs necessary syntax translations into EnergyPlus material entities and XML database containing respective material carbon emission factor. Previously extensive manual translation of building information is now fully automated, and requires zero logistical effort from users.

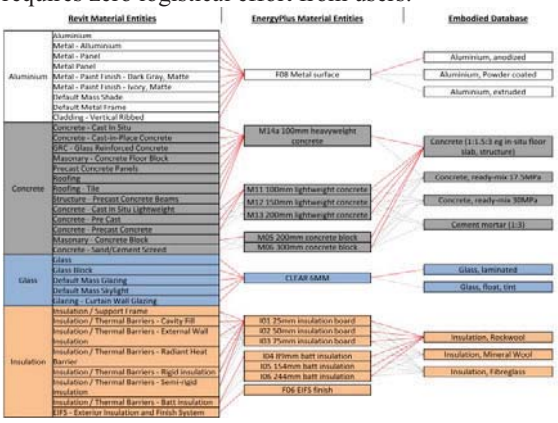


Figure 5 Material association between Revit, EnergyPlus, XML database

Automatic population of missing data for a scalable model

In order to ensure that the new carbon tool is usable for the various stakeholders, the tool directly addresses issues of scalability by adopting first-principles based calculation methods using state-of-the-art energy simulation tool (EnergyPlus) along with heuristic approaches to automatically populate missing data (Fig 6). The use of first-principles approach ensures consistency in carbon computation and therefore directly comparable carbon results across design stages and between stakeholders. However to implement a first-principles based

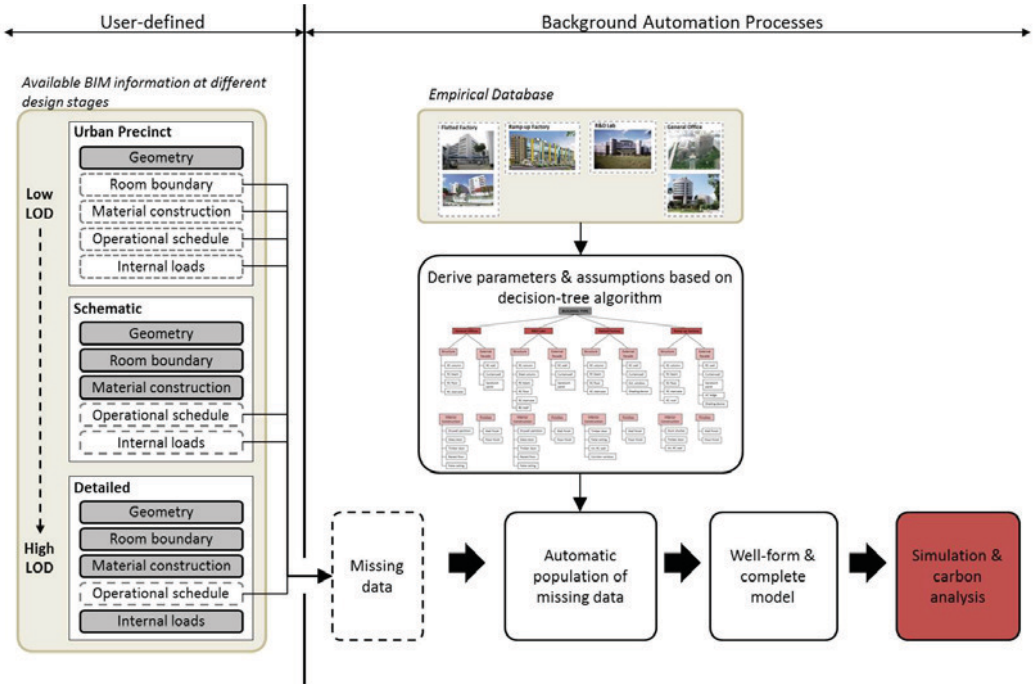


Figure 6 Background automation capabilities

calculation requires detailed building information (material thermal properties, operational schedules, operational loads, HVAC systems), which are often unavailable during early design stages. Government agencies, urban planners, and developers, who often deal with carbon objectives in early planning and design stages, may not be equipped with the necessary building information required to compute carbon.

To enable the new carbon tool to function from physical scales of estate planning, parcel developments, to individual buildings, and deal with varying levels of abstraction, the tool relies on applied heuristics with empirical database to reasonably populate missing data. The database, implemented as an XML-based dataset, contains all empirical assumptions required for early-stage carbon computation and is formulated based on 6 local building surveys. Empirical data comprising of general offices, R&D laboratories, flatted factories, and ramp-up factories, are used as default assumptions for computation. Where information is unobtainable from these audits, local standards and building codes were used as reference. A case-based reasoning approach is implemented to hierarchically organize the data according to real-world building characteristics (Fig 7), where the quality of context-based analysis and assumptions is highly dependent on 1) the breadth and quality of memory and experiences that is being drawn upon, and 2) the correct identification of metrics or indicators that would accurately categorize and predict the missing attributes or information.

A support module, which is part of the SOM, is then developed to facilitate automatic population of missing data. It derives parameters and assumptions from the XML-database, automatically populates any missing information that cannot be obtained from the BIM model, and uses these assumptions as placeholders for carbon calculation to ensure information completeness. This extraction of assumption mimics human experts' analyses (information processing) and considers a variety of information, including building type and various building geometric attributes, much like a human expert would examine building design and drawings to make reasonable assumptions and estimates for missing information. Such context-based datasets though useful in early design stages, are progressively replaced by information retrieved from the BIM model as LOD increases, thereby achieving scalability and ensuring consistent performance assessments across all stages of development.

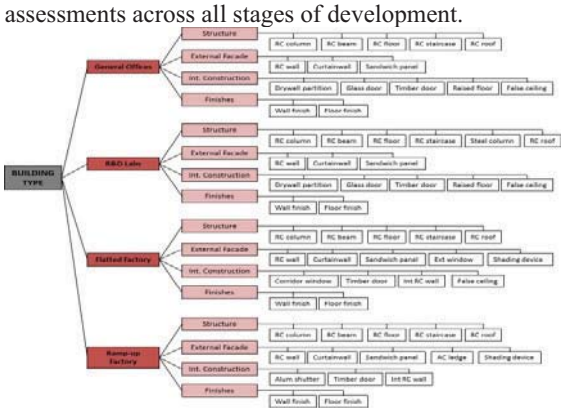


Figure 7 Hierarchical organization of data

The automatic nature of the new carbon tool brings multiple benefits. Previously technically challenging tasks such as digital modelling and parameter definitions for energy simulations are now automated, drastically reducing expert-time in model preparation from a few weeks to a few minutes. Instantaneous carbon analysis can be presented to stakeholders with zero disruption to conventional work processes. Relevant computational capabilities are brought upstream to aid various stakeholders in dealing with carbon computation with varying levels of abstraction.

INTEROPERABILITY

To ensure that the developed tool remains applicable to national interest and industry use, the carbon model is designed to support future extensibility both internally and externally. Given the generality of the SOM which is devoid of any domain specificities, other domain simulations (ie. lighting, urban) can be easily integrated into the carbon model, much like how EnergyPlus simulation tool has been implemented in this first carbon prototype. Each simulation domain will be implemented with an interface module, where the module facilitates the automation of information transfer between the SOM and the simulation input object, and performs necessary syntax adjustments. In achieving extensibility within the new carbon tool, the robustness of the prototype as a design support carbon analytical feature can be incrementally built upon.

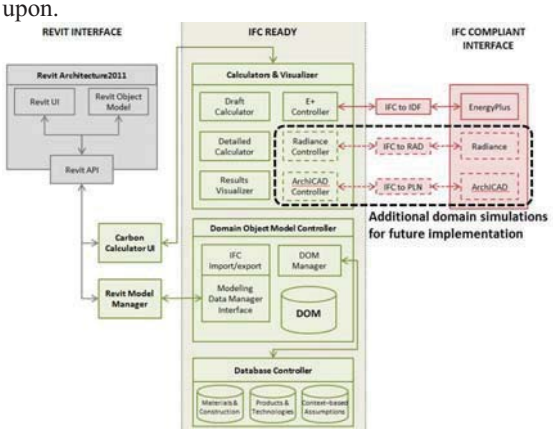


Figure 8 IFC-ready modules for extensibility

Externally, the software technology of the new carbon tool is developed and implemented using Industry Foundation Class (IFC) information schema. Motivation to use IFC schema in the new carbon tool is the need to streamline processes to coincide with national standards, where IFC is recognized as an adopted national standard in Singapore and is widely used to allow overall modularization and interoperability vis-à-vis industry research efforts. Carbon databases, calculation methods, and software modules (data libraries, DOM manager, and controllers) are designed to be well-encapsulated in IFC-ready modules. Technologies developed in this project can be easily deployed in other IFC-compliant software tools. Where future advancements in technology allows more prevalent design modelling tools such as Sketchup, Microstation, and ArchiCad to support IFC format, the carbon prototype can be readily adopted and integrated with these modelling tools; thereby allowing immediate and readily-deployable carbon computation technology to the building industry without any changes to current resources, manpower, capabilities, or work processes. IFC-ready databases also allow for extensibility and adaptability across multi-stakeholders. The database can be easily maintained and constantly updated when better localized carbon data becomes available. These databases can thereafter be shared and extended across different stakeholders, eliminating the need for replication of similar information and allowing compatibility and relevance of carbon results. Enhanced interoperability technologies potentially eliminate previously intermediary processes that are considered tedious, time consuming, and high-expertise tasks. Different industry players are likewise no longer compelled to learn new software approaches and technicalities in order to work different information schema.

USE-CASE DEMONSTRATION

As proof-of-concept of the scalability of carbon model and the reliability of the automation approach and robustness of adopted carbon database, demonstration by means of a set of use-case scenario (representing multi-stakeholder design activities) is shown below. This set of use-case scenario simulates the typical design workflow and design activities spanning from zone/urban precinct planning to conceptual formulation of design massing to finalized detailed design stages. At urban precinct level and assuming the role of agencies and urban planners, different planning configurations (through geometrical massing drawn in Revit) are explored. Urban carbon mitigation strategies (energy offset by photovoltaic panels, carbon sequestration by greenery) are likewise tested. Two types of carbon analysis are presented: 1) incremental carbon chart analysing the effects of carbon mitigation strategies, and 2) total carbon comparison between massing. Computed carbon emission for each massing are allocated as carbon budget and forms the baseline carbon targets for carbon tracking across design stages. Carbon targets stipulated in urban level are brought forward to schematic and detailed design stages. With progressive design activities, the carbon model incrementally replaces previously used placeholders with actual BIM data for carbon computation. Actual EnergyPlus simulation is likewise performed in detailed design stages. Assuming consistency in building type, building geometrical form, and load assumptions, a comparison of carbon emission between masterplan

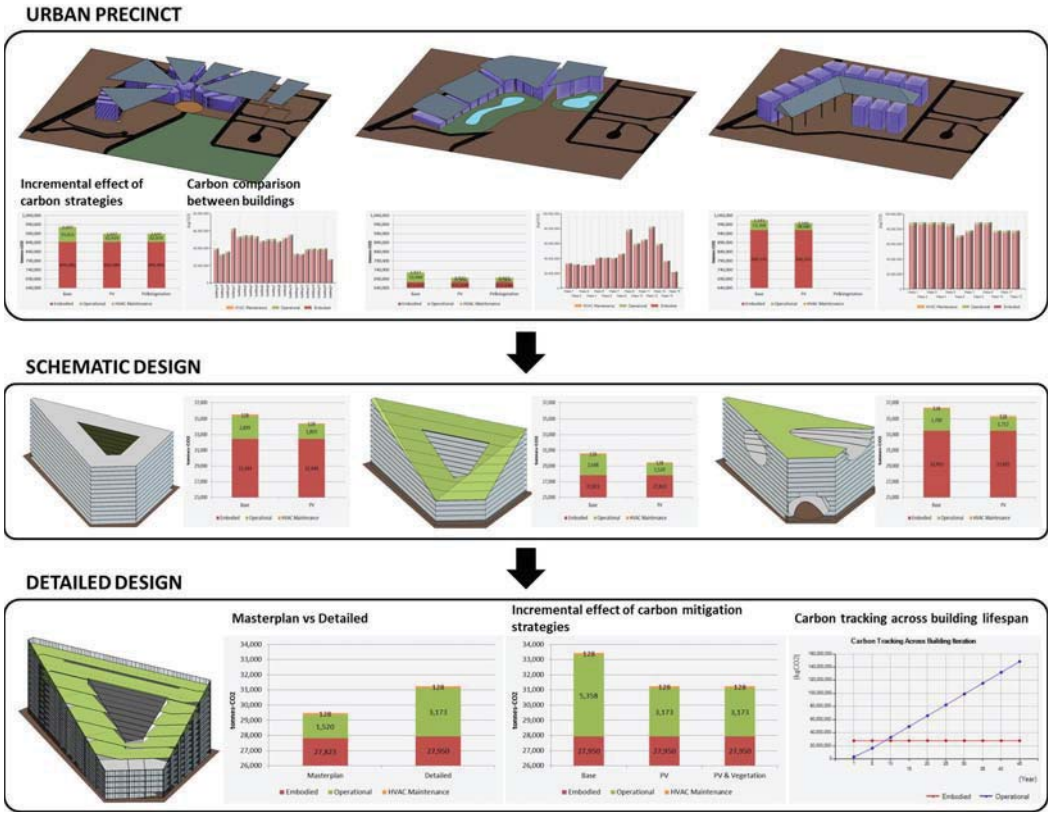


Figure 9 Use-case demonstration of carbon computation across design stages for multi-stakeholders

(applied heuristics using empirical carbon database) and detailed stages (uses BIM information and EnergyPlus) showed only 5% deviation. This is indicative of the dependability of developed carbon model where even with limited building information in early stages, carbon emission can be computed and presented to stakeholders with a high confidence level. Carbon methods are reasonably accurate and carbon results are impactful enough to allow for carbon benchmarking and decision making.

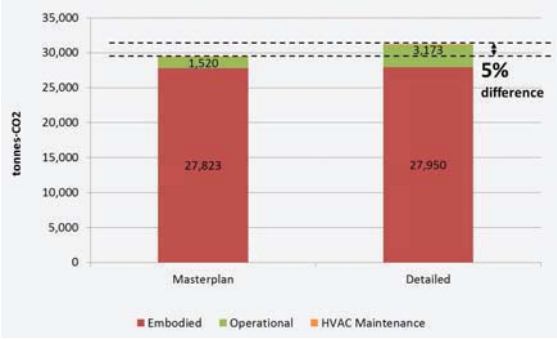


Figure 10 Caron difference between masterplan (heuristics) & detailed design (EnergyPlus)

CONCLUSION

This paper is demonstrative of the computational technologies implemented in the new carbon tool to support multi-stakeholder carbon computation needs and help maintain carbon perspectives across planning and design stages. Enhanced automation capabilities to enable efficient management of previously daunting intermediate processes such as preparation of full EnergyPlus simulation ensures minimal disruption to current work practices and introduces minimal user intervention to compute carbon. While fundamental and working technological framework has been developed, additional effort in building up a more robust and comprehensive database will futher enhance carbon computation capabilities in the new carbon tool. The main idea of future work is to support carbon computation for a wider range of building types apart from the 4 stated types, and provide the same carbon computation capabilities to more building stakeholders (structural engineers, contractors, etc).

ACKNOWLEDGMENT

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INTELLIGENT ENERGY MANAGEMENT SYSTEM (i.ems): VERIFICATION OF AN ALGORITHM FOR REDUCING ENERGY CONSUMPTION ON VARIABLE REFRIGERANT FLOW

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ABSTRACT

A control system on variable refrigerant flow (VRF) has been developed for reducing energy consumption. The effectiveness of this system has been verified by testing in several facilities in Japan and Singapore. The algorithm for this system enables VRFs to maintain the coefficient of performance at a higher level than that achieved by conventional operation. This could be achieved by monitoring and controlling the operational mode of VRFs. The energy saving by this system was up to 30% compared with other conventional facilities in Japan and 15% in Singapore.

INTRODUCTION

According to the statistics by Energy Conservation Center Japan as illustrated in Figure 1, air-conditioning dominates 28% of the energy consumption volume (primary energy conversion) in common office buildings. In Singapore, more than half of energy is consumed by air conditioning. The majority of small or medium-sized buildings built after 1990 in Japan are equipped with variable refrigerant flows (VRFs) as air-conditioning systems.

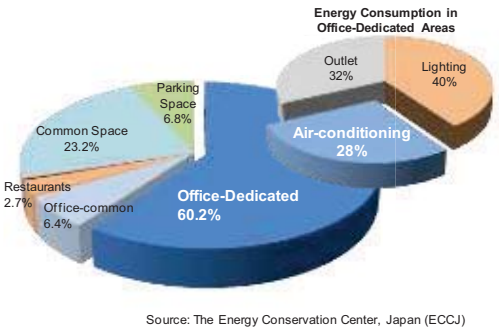


Figure 1 Energy consumption in office buildings

Energy management of buildings with VRFs is not sufficient, because superintendents are not required for almost of such small or medium-sized buildings. In addition, the effect of energy-saving measures in facilities with VRFs, such as sprinkling water over outdoor units during cooling, has not been verified very well.

As a measure for saving energy that is effective for small or medium-sized buildings, an intelligent energy management system (i.ems) for VRFs and its verification because of field operations at the library space of University in Yokohama, Japan and the office space of a company in Hokkaido, Japan and Singapore is described in this paper.

CHARACTERISTICS OF VARIABLE REFRIGERANT FLOW

The analysis on the partial load characteristics of VRFs indicates that COP of VRFs drops sharply when the partial load rate drops below 0.5. The analysis on the operational characteristics of VRFs indicates that VRFs are operated with less than half the rated power consumption most of the time, i.e., VRFs tend to be operated at the low COP most of the time.

The partial load characteristics of a VRF with 16 kW cooling capacity installed in a work place at the Institute of Technology of Shimizu Corporation is illustrated in Figure 2.

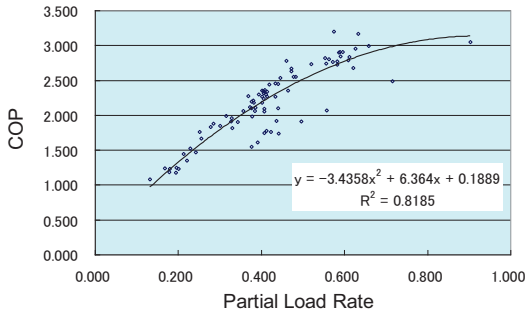


Figure 2 Partial load characteristics of VRF

During the examination period, the power consumption of outdoor units, the suction air temperature of outdoor fans, the discharge air temperature of outdoor fans, the room temperature and the other factors were measured every minute.

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The coefficient of performance (COP) was calculated from the results. The horizontal axis of Figure 2 indicates the partial load rate when considering the cooling capacity of 16 kW of VRF as 1, and the vertical axis indicates the COP. When the partial load rate is 0.9, the COP is 3.1, while the COP drops sharply when the partial load rate drops below 0.5.

The power consumption of VRFs in a library of a university, where four VRF systems are installed in a large room, is illustrated in Figure 3. The effective power of outdoor units per minute was measured for the power consumption. Figure 3 indicates the total operation time (vertical axis, minutes) running with every 1 kW of power consumption (horizontal axis). Each VRF was operated with less than half the rated power consumption most of the time as indicated in Figure 3.

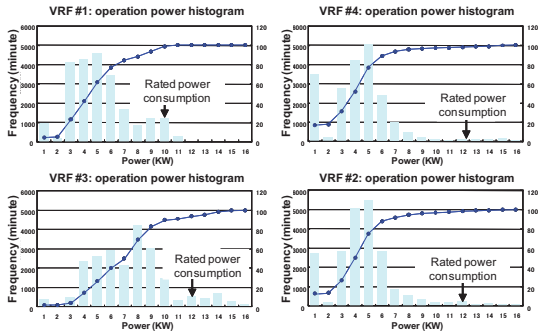


Figure 3 Operational Outline of energy saving control algorithm

ENERGY-SAVING CONTROL ALGORITHM

The management system enables VRFs to maintain the coefficient of performance at a higher level than that by conventional operation. This could be achieved by monitoring and controlling the operational mode of VRFs. The outline of i.ems is illustrated in Figure 4. VRFs keep the operation at higher rate of partial load by i.ems that monitors the operational status of the VRFs from the outside and judges its operational status.

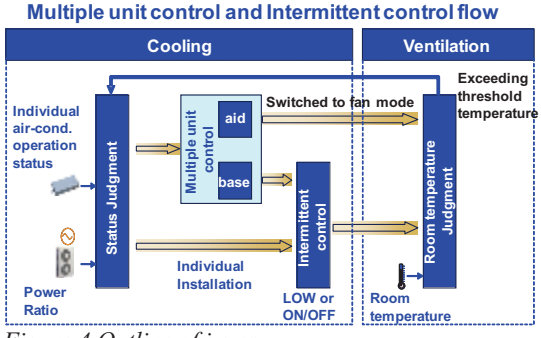


Figure 4 Outline of i.ems

The rated power ratio of the primary side of outdoor unit was used for the evaluation of the operation status of VRFs. The rated power ratio can be calculated by dividing the measured power consumption or effective value per minute by the rated power consumption.

Compared with the previous values of the rated power ratio, the operation status is set as one of seven stages: "start-up," "high load," "medium load," "low load," "ON/OFF, "stop," and "restart." According to the data pre-entered in i.ems, "intermittent air-conditioning" is selected when one VRF is installed in one space, and "multiple unit control" when more than two VRFs are installed in one space.

When “multiple unit control” is selected, each VRF is designated to be either "base" or "aid”. The rated power ratios of the VRFs are constantly monitored by the system, and when the operational condition changes from "stop" to "start-up," energy saving mode starts. Until the room temperature becomes stable, both "base" and "aid" VRFs are operated, and after the threshold time, the operation mode of "aid" is changed from cooler mode to fan mode and the cooling load processed by "aid" shifts to "base”. However, the room temperature covered by "aid" is constantly monitored, and when exceeding the allowable temperature, the operation mode is switched from fan mode to cooler mode. Moreover, even "base" is switched to fan mode when it is determined to be "low load" or "ON/OFF." For intermittent air-conditioning, the VRF is controlled as "base."

The air-conditioning evaluation system on a Web site was used so that users can evaluate the validity of the allowable temperature and the algorithm itself, the responses is monitored at any time during the experimentation. The system configuration of this control system for saving energy consumption of VRFs is illustrated in Figure 5. This system can be realized by connecting a general-purpose PC and the centralized

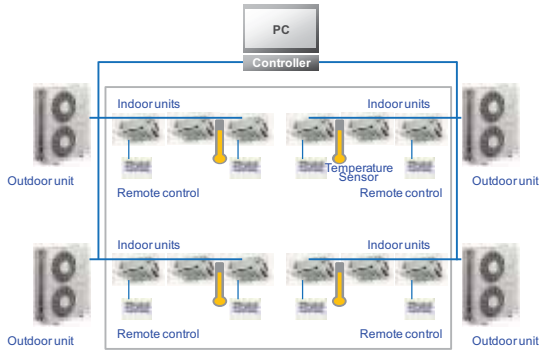


Figure 5 System configuration

VERIFICATION OF ENERGY-SAVING CONTROL ALGORITHM

The results of verification of this energy-saving control algorithm in three facilities, a library space of a university in Japan, and office spaces in Japan (Masahiro et al. 2007, Katsuhiro et al. 2009) and Singapore are described.

Library space of university in Yokohama, Japan

The verification took place in an open-stack room on the third floor of a university library building (a three-storied reinforced concrete building). The layout of this room is illustrated in Figure 6. This is a large room with a floor area of 544 m^2 without partitions, which is divided into a storeroom and a browsing space. Each space has two VRF systems, four systems in total.

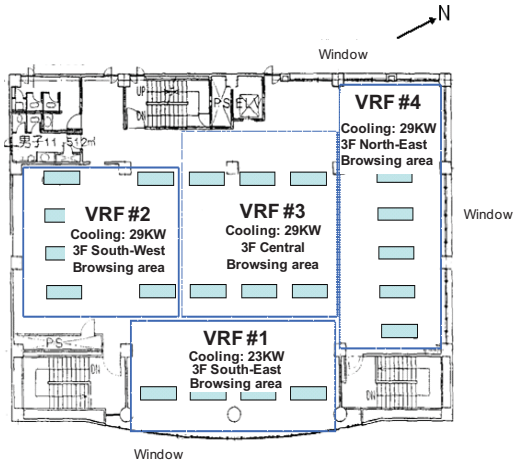


Figure 6 Verification field (University library)

A power sensor was set up for each outdoor unit, and the effective power and room temperature on the top of tables were measured for verification. For multiple unit control mode, the VRFs in the browsing area were designated as "base," and those in the storeroom were controlled as "aid".

Verification was carried out from mid-July to the end of September, by alternatively repeating two patterns of operation, i.e., without any control and with multiple unit control. The set temperature was 26°C and the allowable temperature was 28°C, respectively, for the four systems throughout the tested period.

The rated power ratios, power consumption/rated power consumption for VRFs, are illustrated in Figure 7 along with the data taken on the days without multiple unit control. The power consumption of the four systems without control is high at start-up, however, the rated power ratios of all four systems drop to 30 to 40% after 11:00 due to the so-called wait-and-see operation. On the other hand, when multiple unit control is activated, the four systems work together at start-up, but later, while the VRFs in the browsing area are operating as base, the VRFs in the storeroom repeat on and off properly, and the rated power ratios are high on the whole.

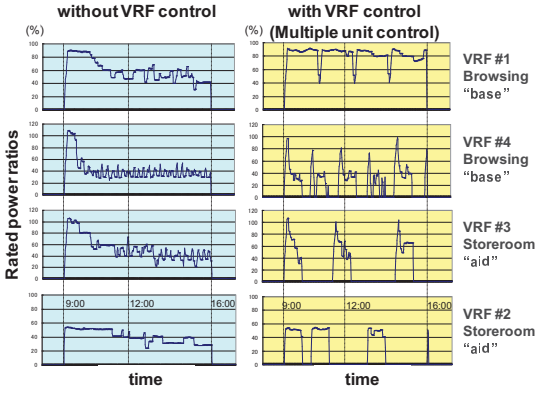


Figure 7 Rated power ratios with/without VRFs control

The distribution of the power consumption, i.e., the sum of products of power consumption when the VRFs are in operation in the floor area by day, is illustrated in the lower part of Figure 8 along with the daily average ambient temperature. The squares represent the days without control and the triangles represent the days with multiple unit control. There is a clear difference in energy consumption between with and without control. The solid lines in the as 0.6 and 0.8, so that it is concluded that the power consumption per square meter can be predicted from the daily average ambient temperature.

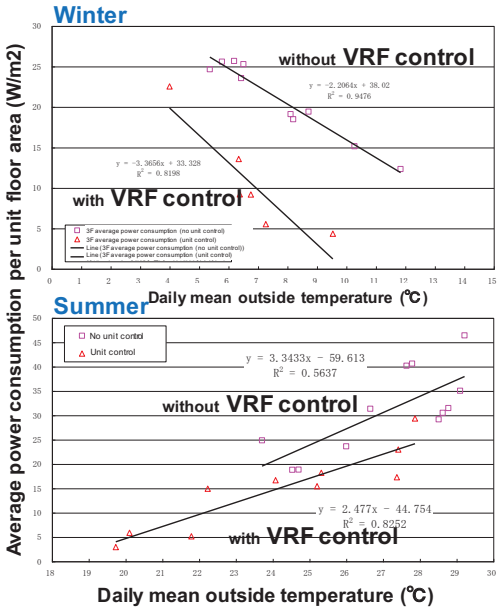


Figure 8 Verification results in summer and winter (University Library)

On the other hand, one might be worried about the deterioration of the room temperature distribution caused by switching the cooler mode to fan mode under multiple unit control. The daily average room temperatures under no VRF control and under multiple unit control are described in Table 1. The space-time average room temperatures were the same, both 27.5°C.

Table 1 Verification results of temperature in summer (University library)

Average Room Temperature without VRF control

Date	Browsing Room South-East	Browsing Room North-East	Store Room South-West	Store Room Central	Daily Average
2006/08/08	28.4	28.8	26.8	27.3	27.8
2006/08/09	28.2	28.8	26.8	27.3	27.7
2006/08/22	28.0	28.6	26.5	27.1	27.5
2006/08/23	28.1	28.5	26.4	27.1	27.5
2006/08/25	27.7	28.3	26.4	26.9	27.3
2006/08/28	28.0	28.8	26.7	26.9	27.6
2006/08/30	27.6	28.1	26.2	26.7	27.2
Average	28.0	28.6	26.5	27.0	27.5

Average Room Temperature with VRF control

Date	Browsing Room South-East	Browsing Room North-East	Store Room South-West	Store Room Central	Daily Average
2006/09/05	26.9	28.6	27.4	27.7	27.6
2006/09/06	25.9	28.5	27.5	27.7	27.4
2006/09/07	27.0	28.5	27.1	27.5	27.5
2006/09/08	26.3	28.4	27.2	27.6	27.4
2006/09/19	26.3	28.5	27.3	27.3	27.3
2006/09/20	26.8	28.7	27.6	27.6	27.7
2006/09/21	26.5	28.4	27.8	27.5	27.5
2006/09/22	26.0	28.5	27.6	27.3	27.4
2006/09/28	26.6	28.2	27.3	27.2	27.3
Average	26.5	28.5	27.4	27.5	27.5

Verification was carried out also in winter from early December 2006 to the end of January 2007, using the same pattern of operation as used in summer. The set temperature and the allowable temperature were 20°C and 20.5°C, respectively, for the four VRF systems throughout the period. The distribution of the power consumption per square meter during heating along with the daily average ambient temperatures is illustrated in the upper part of Figure 8. As found in cooling, we can see a difference in energy consumption between with and without VRF control, and a strong correlation between the daily average ambient temperature and the power consumption per square meter.

The space-time average room temperatures were a little bit lower under multiple unit control. This was because the compressor was off until the room temperature reached below the allowable temperature.

When totaling the assumed power consumption by day obtained by multiplying the power consumption per square meter, which is calculated by substituting the daily average ambient temperatures from June 1 to October 31 (in 2006, only on working days), for the regression equation indicated in Figure 8 by the floor area of 5000 m^2 and an operation time of 8 hours during the verification period, the sum is 79,080 kWh when operated without control, and 56,309 kWh under multiple unit control, resulting in an assumed energy-saving rate of 28.8%.

On the other hand, when calculating the same for working days from December 1 to March 31 for heating, the power consumption is 61,810 kHz when operated with no control, and 22,608 kWh under multiple unit control, resulting in an assumed energy-saving rate of 63.4%. However, the room temperature could not be maintained at an even rate during the experiment. If the effect of multiple unit control is the same as that in summer, the rate can be expected to be at least 30%.

Office space in Hokkaido, Japan

The VRFs at office spaces in Hokkaido comprise four systems. Three systems cover the first to third floors, and one system covers a part of the office and a small room on the second floor. All four systems have the same air conditioning capacities: 50 kW for cooling. Verification took place from January to March 2008 for winter, and from July to September 2008 for summer.

The results of verification during summer period are illustrated in the lower part of Figure 9. The distribution of the power consumption, i.e., the sum of products of power consumption when the VRFs are in operation in the floor area by day, along with the daily average ambient temperature is illustrated in Figure 9.

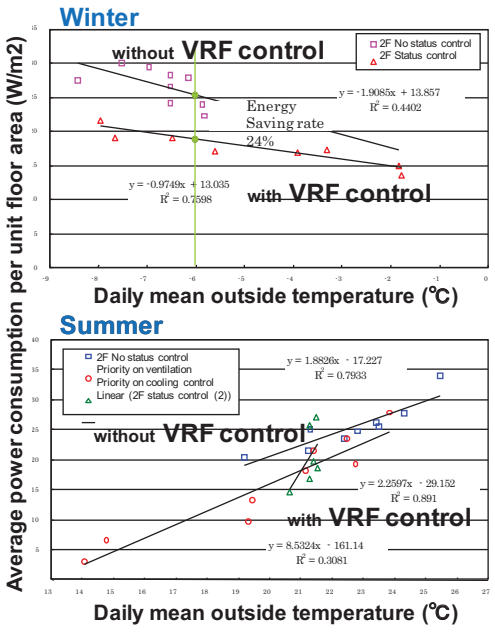


Figure 9 Verification results in summer and winter (Office space)

When controlled by the algorithm giving priority to cooling, as this forced the indoor units originally used for the fan operation to switch to the cooling operation, energy consumption increased compared with no control mode. However, when using the algorithm giving priority to fan operation, the energy-saving rate was approximately 20% at a daily average ambient temperature of 21°C. The allowable temperature was set to 23°C.

The results of verification during the heating period are illustrated in the upper part of Figure 9. In the chart, the pink squares represent the results under no control, and the red triangles represent those under control.

When the average ambient temperature was -6°C, the energy-saving rate was approximately 24%. The control temperature was left to users' discretion and the allowable temperature was set to 27°C.
Assumed power consumption for each period was calculated by using power consumption per square meter obtained from the linear regression equation in Figure 9. Assumed power consumption was calculated by substituting daily average ambient temperatures for the heating period (from November 2007 to March 2008) and for the cooling period (from July to September 2008). Assuming floor area was 5000 m^2 and the air-conditioning time was 10 hours.

For heating, power consumption under no control was 81,643 kWh, and 65,010 kWh under control, which makes the energy-saving rate throughout the period approximately 20%. For cooling, it was 64,411 kWh under no control, and 53,053 kWh under control, and the energy-saving rate was approximately 18%.

Office space in Singapore

The VRFs at office spaces in Singapore comprise four systems. Each systems have the following air conditioning capacities: 11.3kW x 2, 14.1kW x 2, 19.1kW, and 12.8kW for cooling. Verification took place from September 2012 to January 2013. The allowable temperature was set to 26°C. Assuming floor area was 940 m^2. The results of verification from Monday to Friday are illustrated in Figure 10. And the comparison of power consumption per unit floor area in Japan and Singapore at the allowable temperature to 26 ° was illustrated in Table 2.

Singapore has higher humidity than Japan, and the power consumption per unit floor area at 26 °C is four times higher (103.4W/m^2) in Singapore than that (27.3W/m^2) in Yokohama without i.ems control. With i.ems control, energy-saving rate was approximately 15% in Singapore.
Energy saving rate with i.ems control is lower in Singapore than in Yokohama, however, summer season is much longer and there may be possible that power saving in Singapore through one year will be much higher than in Japan.

This i.ems system was originally invented for Japanese climate with summer and winter, however, was found out by this trial to be adopted to tropical climate like in Singapore.

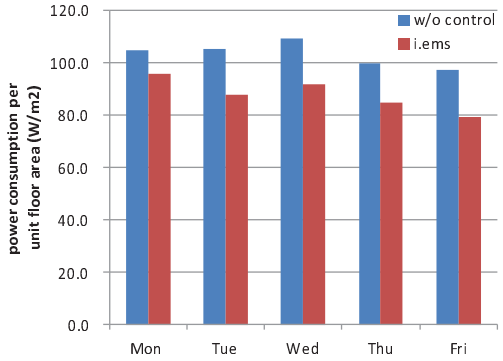


Figure 10 Verification results in Singapore

Table 2 Verification results of power consumption per unit floor area in summer at 26 °C

Location	Yokohama	Hokkaido	Singapore
w/o control W/m^2	27.3	31.7	103.4
i.ems W/m^2	19.6	29.6	87.9
Energy saving	28%	7%	15%

CONCLUSION

The effect of energy-saving algorithm i.ems for VRFs has been verified by applying its control system to the operation of actual facilities, and has been analysed to be significant.

The analysis on the partial load characteristics and the operational characteristics of VRFs indicates that VRFs tend to be operated at the low COP most of the time.

The energy-saving control algorithm enables VRFs to maintain the coefficient of performance at a higher level than that achieved by conventional operation by monitoring and controlling the operational mode of VRFs is developed and applied for the library space and office space.

The result of verification of i.ems indicates significant difference in energy consumption between no VRFs control and VRFs control, both in the summer and winter seasons.

By calculating the power consumption in summer and winter using the linear regression equation obtained from field verification, the energy-saving effect by multiple unit control at university library is analysed to be approximately 30% for both summer and winter. At the office in Hokkaido, it is analysed to be approximately 20% for both summer and winter.

At the office in Singapore, it is analysed to be approximately 15% energy saving for humid tropical summer. Energy saving rate with i.ems control is lower in Singapore than in Yokohama, however, summer season is much longer and there may be possible that power saving in Singapore through one year will be much higher than in Japan.

This i.ems system was originally invented for Japanese climate with summer and winter, however, through this trial, was found to be adaptable to a tropical climate like in Singapore.

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NOVEL EVAPOTRANSPIRATION- ENHANCED ROOF GARDEN

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ABSTRACT

A novel roof garden with enhanced evapotranspiration function to effectively mitigate urban heat island phenomenon has been developed. In order to select suitable soil and plant species for the garden, water retention capacity of six soil specimens and transpiration rate of seven plant species were examined. The results showed that perlite soil with organic matter had higher water retention capacity than other soil specimens, and the transpiration rates of herbaceous flowers, such as gazania and dianthus, were greater than that of other species. It was also observed that the moisture content in the soil at 50 % of soil water retention or greater was necessary to maintain high evapotranspiration rates. Effects of roof garden on thermal environment were also experimentally evaluated. The heat transfer into the ceiling under the roof garden was reduced to one tenth of that without it. This suggests that the roof garden has a potential to reduce the indoor cooling load.

INTRODUCTION

Urban heat island phenomenon is becoming noticeable in large cities around the world, which must increase the energy consumption and deteriorate the public health in cities. Installing roof gardens is one of the effective countermeasures to mitigate urban heat island phenomenon, because it is expected that roof gardens can effectively reduce the heat accumulation in the buildings through evapotranspiration of plants and soil. However, there have been only a limited number of studies on roof garden system focusing on evapotranspiration. In order to develop the roof garden with enhanced evapotranspiration function, basic data on water retention capacity of soil materials for roof garden and on transpiration of plants have to be obtained. Even though there are numbers of previous studies on transpiration of trees and crops, the transpiration of plant species used in roof gardens such as herbaceous flowers and sedum has not been studied very much. In the present study, we conducted several experiments to evaluate the water retention capacity of soil materials for roof garden, and the transpiration of plant species utilized in roof gardens. Based on the experimental results, we have developed the Evapotranspiration-Enhanced Roof Garden, which has a novel structure and function to accelerate the effects of evapotranspiration of vegetative layer. In order to select the suitable soil and plant species, water retention capacity of six soil specimens and transpiration rate of seven plant species were examined. Based on the experimental findings and observations, a prototype roof garden was designed and constructed for the purposes of evaluating the effects on thermal environment.

WATER RETENTION CAPACITY OF SOIL AND TRANSPIRATION OF PLANTS

Green space reduces surrounding air temperature by providing the shading and through evapotranspiration from soil and plants. Transpiration intensity varies depending on plant species and environmental condition. For instance, the transpiration rates of turf (*Zoysia matrella*) were reported 5 L m^{-2} day^{-1} on the roof garden[1)]. The transpiration rates of ginkgo (*Ginkgo biloba*) that had 32 m^2 of canopy area, and oriental plane (*Platanus orientalis*) that had 19m^2 of canopy area were 452 L day^{-1} and 378 L day^{-1}. Respectively, on sunny day in August[2,] on the ground, a tree extends its roots deep into the soil, absorbs water through the roots, and transpires the water vapor through its leaves. There was a limit in thickness of the soil (plant foundation) used in a roof garden due to structural restriction.

Experiment 1: Measurement of water retention capacity of soil for roof gardens

Water retention capacities of six specimens of artificial and natural soil used in roof gardens were examined. These being perlite soil with organic, perlite soil, a volcanic gravel soil, an organic soil, an ando soil (Kuroboku soil) and a granite soil (Masa soil). The first four specimens were artificial soil while the last two are natural soil. Each soil specimen was put into a separate pot, and all the pots were kept in a growth chamber (LPH-0.5P-NC-5; Nippon Medical & Chemical Instruments Co., Ltd) that was capable of controlling the air temperature and relative humidity. Air temperature and relative humidity were set at 30 °C and 60 %, respectively (Table 1). The quantity of water retained by each soil specimen was estimated as the difference between the initial mass, which was measured after enough irrigation was made to the pot, and the final mass, which was measured when evaporation was no longer observed.

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The results were shown in Figure 1. The quantity of water retained by the decomposed granite soil was the lowest in the six specimens examined and that of ando soil was the highest. The quantities of water

Table.1 Experimental conditions

Air temperature	30 ℃
Relative humidity	60 %
Lighting	—
Pot size	150×150×200 mm (Made of vinyl chloride)

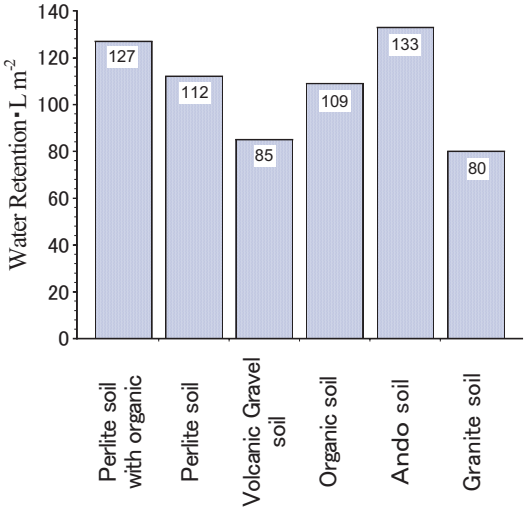


Figure1 Water retention capacity of soil for roof garden

retained by both of the perlite soil specimens were slightly less than the ando soil, but greater than the rest. In the design of roof gardens, load to the roof must be taken into consideration. Since perlite is a lightweight material and has good water-retaining characteristics, we concluded that the perlite soil was the most suitable material for roof gardens.

Experiment 2: Measurement of plant transpiration

To obtain the basic data on transpiration of the plants commonly used in roof gardens, transpiration rates of seven plant species were measured. Petunia (*Petunia×hybrida*), gazania (*Gazania splendens* 'Day break'), verbena (*Verbena hybrida* 'Hanatemari'), dianthus (*Dianthus hybridus* 'Telstar '), hypericum (*Hypericum calycinum*), turf (*Zoysia matrella*), Mexican stonecrop (*Sedum mexicanum*) were selected for the experiment. The experimental conditions were shown in Table 2. Each plant was planted separately in a pot and all the pots were set in growth chamber in which the ambient temperature, relative humidity, light intensity, and photoperiod can be controlled (Photo 1). An artificial soil with perlite was used in the experiment. The pot without plant was also prepared as the control. Two pots for each species were assessed in the experiment. The pots were set in the growth chamber after enough irrigation, and change in the weight of each pot was monitored once a day at a pre-determined time. The measurement continued until the plant began withering. The monitoring was repeated 10 times for each plant species.

Table.2 Experimental conditions

Air temperature	Light period 30 °C, Dark period 25 °C
Relative humidity	Light period 65 %, Dark period 70 %
Lighting	150 W m^{-2}
Photoperiod	Light period 14 h, Dark period 10 h
Pot size	150×150×200 mm 150×150×100 mm (turf, mexican stonecrop) (Made of vinyl chloride)
Soil	Perlite soil with organic matter (K-soil : Taiko Trading Co., Ltd.)

The experimental data on transpiration rates are shown in Figure 2. During the first 24-h period, the average transpiration rates of verbena, petunia, gazania, and dianths were more than 15 L m^{-2} day^{-1} and higher than those of other species. However, the rates of these four species decelerated rapidly fourth through sixth day after. Gazania and petunia withered after seven days and eleven days, respectively. Verbena and dianthus withered after ten days. The transpiration rate of hypercom was 6-7 L $m^{-2}day^{-1}$ until the 6th day, and decreased gradually after the seventh day. Hypercom withered on the fifteenth day. The transpiration rates of sedum, turf, and the control (no plant) were approximately 5 L m^{-2} day^{-1} on the first day and decreased gradually after the second day. Turf withered on the thirteenth day, and Sedum withered on the fifteenth day. The experimental results showed that the transpiration of herbaceous flowers was higher than that of other species. The transpiration of flowers was almost two or three times greater than that of turf and sedum in our



Photo 1 Measuring of plants transpiration in a growth chamber

experiment.

We observed that the herbaceous flowers withered on the fourth or fifth day. This could be due to decreased water content in the soil. The rate of cumulative transpiration for quantity of soil water retention is shown in Figure 3. The rate of cumulative transpiration of four herbaceous flowers achieved 50% on fourth through sixth day, when these herbaceous flowers withered. These results suggest that the flowers could perform high transpiration by maintaining the rate of soil moisture of greater than 50% for total soil water retention.

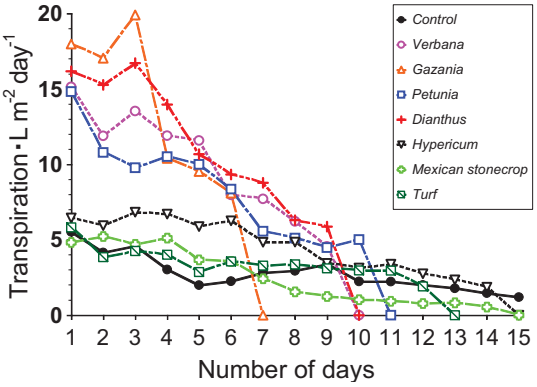


Figure 2 Variation of plants transpiration

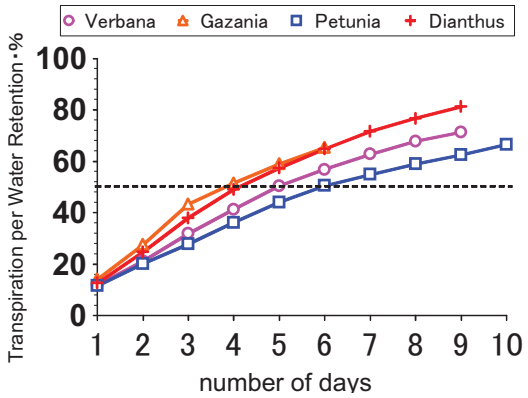


Figure 3 Cumulative Transpiration per Quantity of Soil Water Retention

DEVELOPMENT OF THE SYSTEM FOR EVAPOTRANSPIRATION ENHANCEMENT

Structure of the system

The experimental results on water retention capacity of soil specimens and transpiration of plants suggest that the following points are critical in designing the evapotranspiration-enhanced roof garden system.

1) Use of perlite lightweight artificial soil
2) Selection of herbaceous flower with high transpiration rate
3) Implementation of irrigation management system to maintain water content in the soil at or greater than 50 % of soil water retention quantity all the time

High frequency irrigation is a solution to maintain a high water content in the soil. However, excess irrigation increases a risk of disease and/or insect damage. Since used of tap water for irrigation means increase in carbon footprint, the consumption of tap water should be minimized. Thus, we developed an irrigation management system using sensors and rainwater storage.

A new roof garden system developed here solved these problems.

Cross-section diagram of the system is shown in Figure 4. Water for irrigation is stored in the water-holding layer, which is under the plant layer and is lined with water-impervious sheet. The water level of the water-holding layer is continuously monitored. If rainfall is not sufficient, the minimum amount of tap water is replenished to the water-holding layer. Watering to the plant layer is conducted through the water-holding layer using the roof inclination. Water supply is controlled with a water-level sensor equipped at the lowermost part of the inclination. When the water-holding layer is filled with water, water supply is stopped. We do not need irrigation pipes for this roof garden system, and excess water supply for irrigation is avoidable unlike in case of manual irrigation or sprinkler irrigation. Water supply starts, when water is dry up in the tap water-holding layer. Water supply will not be conducted until water is remaining in the water-holding layer due to rainfall. Therefore, this system allows us to minimize the use of tap water. Some water in the water-holding layer is moved to the planting layer through water supply sheets by capillary action. Storing water edge is put at 2 m intervals on the roof

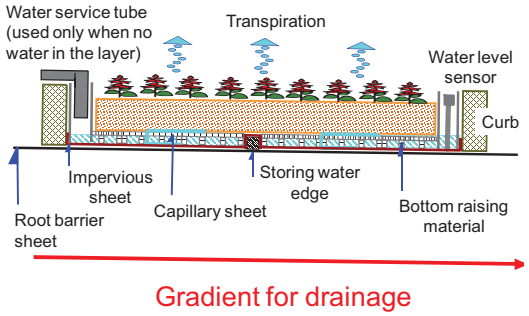


Figure 4 Cross section diagram of the system

in order to increase the capacity for stored water.

Verification of water storage

The novel roof garden design was experimentally evaluated for its water storage capability on the roof of an existing concrete building at Nishichofu



Photo 2 Plant cultivation experiment on the roof

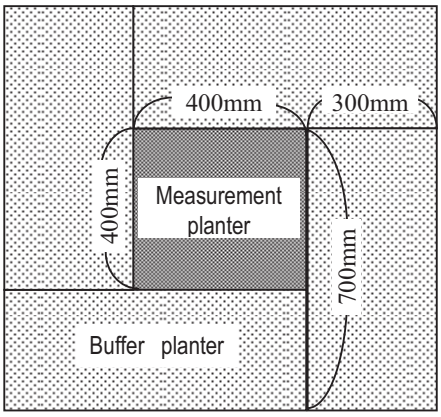


Figure 5 Layout of the planters

Complex of Kajima Technical Research Institute, Japan（Photo. 2. The roof was located at 16 m high. The experimental period was between January and December in 2008. The square-shaped experimental ward was composed of of one measurement planter (400 x 300 x 300 mm) in the middle and surrounding four buffer-planters (700 x 300 x 300 mm each) (Figure 5). The buffer planters were installed in order to remove influence of heat and wind from the outside. Transpiration rate of the plants were measured gravimetrically by weighing the mass of the measurement planter.

The results are shown in Figure 6. The initial mass was measured on August 10, 2008 after the planter had been well irrigated. During the first 5 days, little differences were observed in daily transpiration rate. Transpiration rate was decreased from day 6 in the conventional system, but a decrease in transpiration was suppressed by developed system.

PROTOTYPE EXPERIMENT

Materials and methods

We conducted a prototype experiment of evapotranspiration accelerating system for roof garden to evaluate the effect on thermal environment. The prototype roof garden was constructed on a roof of another existing concrete building at Nishichofu Complex. The roof was located 10 m high. The experimental period was between January and December in 2011. The size of the roof garden was 6000 x 5000 mm, and the thicknesses of water-holding layer and planting layer were 50 mm and 100mm, respectively. The surface of planting layer was covered with 20mm-thick artificial aggregate (MESALAITE fine aggregate) to prevent flying of soil particles. Dianthus (*Dianthus superbus* ' Kahori'; 90 plants), gazania (*Gazania splendens* 'Day break'; 80 plant), begonia (*Begonia semperflorens*; 80 plants), and verbena (*Verbena hybrida* 'Hanatemari'; 54 plants) were planted on the planting layer (Photo 3).

Air temperature, relative humidity, precipitation, wind speed and wind direction at 2000 mm above the roof surfaces were monitored utilizing a weather station (Vantage Pro2 , Davis Instruments). Measurement items are shown in Table 3 and the layout of sensors set in the garden is shown in Figure 7. The same measurements were made on the roof

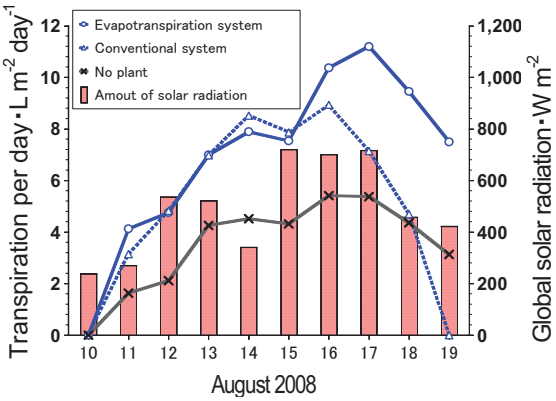


Figure 6 Comparison of transpiration with the conventional system and evapotranspiration Enhanced system

Table 3 Measurement items

Measurement	Roof garden	Control
Temperture	Soil surface, under garden	Surface
Heat flow	Soil surface, under garden	Surface
Soil moisture	4 points	—
Albedo	1 point	1 point
Ceiling temperture	Surface	Surface
Ceiling heat flow	Surface	Surface
Ceiling surface below 100mm temperture	1 point	1 point
Room temperture	1 point	1 point



Photo 3 Cultivated Plants Left to Right verbena, begonia, gazania, dianthus

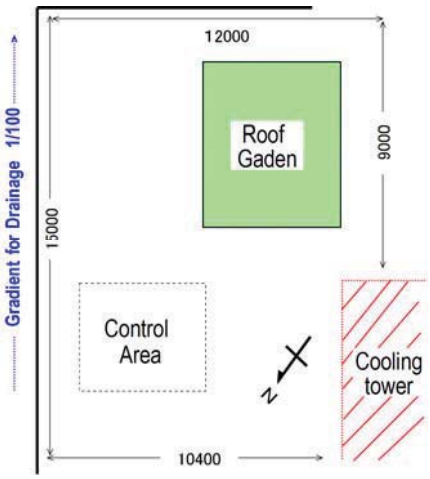


Figure 8 Layout of the demonstration experiment

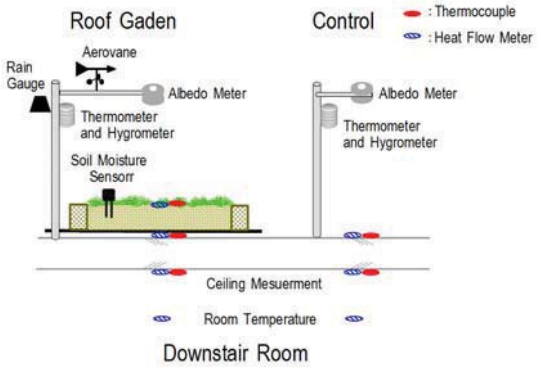


Figure 7 Sensor layout

without garden for comparison（Figure 8）.

Effect on thermal environment

Experimental results on heat transfer of roof and ceiling were summarized in Table 4. The heat flow of the roof surface and ceiling was measured by thermal flowmeters, and the heat transfer was estimated by using the temperature data of the roof, ceiling, and air temperature at the point immediately above.

The heat transfer into the ceiling was reduced by one-tenth on the roof with the roof garden. This result showed that the roof garden has a large effect on heat load reduction for cooling. The heat transfer into the building declined by one-third of that without it. This could be because of the reduction of heat flow into the building and latent heat exchange by roof garden. Heat accumulation of buildings is one of the major factors causing urban heat island phenomenon. Therefore, these results support the effectiveness of roof garden as a countermeasure for urban heat island.

CONCLUSION

Table4Roof-ceiling amount of heat transfer per day summer(Wh m^{-2} day^{-1})

	Rooftop Heat Flow		Ceiling Heat Flow	
	Roof Garden	Control (Concrete)	Roof Garden	Control (Concrete)
Inflow Heat Capacity	480.4	720.9	59.0	408.0
Runoff Heat Capacity	-339.1	-278.6	-15.0	-8.9
Energy Balance	**141.3**	**442.4**	**44.0**	**399.1**

A novel roof garden system accelerating evapotranspiration has been developed. A set of experiments were conducted to obtain the basic data on soil and plants, as well as the configuration. A demonstration experiment was also conducted on the roof garden in order to evaluate its effects on the thermal environment. As a result, the following were confirmed.

1) Transpiration rate of herbaceous flowers was about three times as high as that of turf and soil without plant.
2) High transpiration rate can be maintained when the water content in the soil is more than 50% of soil water retention quantity.
3) The heat transfer into the ceiling was reduced to one-tenth on the roof with the roof garden. The roof garden had a significant effect on reducing cooling load.
4) The heat transfer into the building frame was reduced by one-third by the roof garden, which reduces accumulation of heat in the building frame. Therefore, the roof garden was effective for mitigation of urban heat island phenomenon.

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POST OCCUPANCY LIGHTING ANALYSIS FOR A COMMERCIAL OFFICE BUILDING

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ABSTRACT

This study analyses the key principles in energy efficient lighting design for a commercial office building in India. Detailed assessment of the passive and active design features is carried out and is complimented by in-situ measurements. The results show that the building geometry, orientation & envelope is well planned to permit natural daylight to most of the interior spaces. The use of light shelves is highly effective in this regard. Simulations show that a 78.54% of interior space receives a Daylight factor (DF) of more than 1.9 with light shelves incorporated, as against 52% without the light shelves. It is also noted that the use of T5 luminaries is very efficient in achieving a Lighting Power Density (LPD) of 0.46 W/ft^2. And field measurements show that the office space along south perimeter is sufficiently day-lit than the north, investigation into these are also presented.

INTRODUCTION

The total annual energy use in office buildings varies in the range of 100–1000 kWh/m^{2}yr, depending on the geographic location, use and type of office equipment, operational schedules, use of HVAC systems, type of lighting, etc (Santamouris and Dascalaki 2002). In these buildings, lighting generally constitutes 20–45% of electricity demand but it varies from one building to another (Dubois and Blomsterberg 2011). Research also shows that good number of newer buildings is still not designed in a way that lighting energy is utilized efficiently. It is also found that 23% of all energy-saving opportunities could be achieved by just improving the energy efficiency of the lighting system. One of the proven methods is to exploit the daylight coming into indoor areas more effectively. If the lighting can be automatically turned-off or dimmed according to the varying levels of daylight flowing indoors, the amount of electrical energy consumed for artificial lighting can be thereby reduced. In addition, owing to the decrease of heat gain caused by artificial lighting, cooling energy can be reduced in such office buildings (Aries and Newsham 2008).

The Office campus selected for the study has set a benchmark in terms of energy efficient design and sustainable practices. The high standards achieved here have enabled it to be showcased in the *'Best Practices Guide for High Performance Indian Office Buildings'* by Lawrence Berkeley National Lab, a U.S. Department of Energy (DoE) National Laboratory . Researchers from Technical University of Braunschweig, Germany have also acknowledged the high-energy efficiency and comfort parameters in this building. Over 90% of the office space has natural light, reducing the need for artificial lighting during daytime. The design includes light shelves along all windows to ensure that the natural light travels as deep into the building as possible. This work begins with outline of the scope of study, briefly describes the methodology adopted, chosen building description, climate characteristics and benchmark building guidelines. In another section, actual lighting analysis of active and passive systems are discussed in detail which is complimented through field audit and simulation results. Finally, summary of key findings and recommendations to improvise lighting aspects are also presented.

OBJECTIVES

Given the importance of designing a proper lighting system for energy savings and occupancy comfort especially in work environment, the study is conducted with the following key objectives.

- Analyse the passive design strategies adopted to maximise daylight.
- Evaluate the daylight distribution on the work plane through field measurements.
- Perform comparative study of the daylight penetration and internal illumination with and without light shelves using Integrated Environmental Simulation (IES) software.
- Estimate the lighting power density (LPD) achieved and estimate the potential savings attributed due to lighting fixtures like T8 vs T5 vs LED.
- Justification of right choice for lighting fixture using DIALux simulation.

METHODOLOGY

To fully realize the objectives, a field study using simple lumen method is performed. Both passive and active design features of the building are studied and correlated with the building energy consumption data. In addition, simulations are performed to study the effectiveness of envelope systems such as

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glazing, light shelves and energy efficient lighting fixtures using IES and DIALux.

Building description

Software Development Building 1 (SDB1) as presented in Fig.1 is the chosen office building under study. The building layout is designed according to the solar passive principles along with a high performance building envelope consisting of insulated walls and roof. The windows use high performance double glazed unit with adequate shading components. The width of the office floor plate is restricted to sixteen meters to ensure adequate daylight from the north and south facing windows. The building has a gross floor area of 2, 25, 509 sq. ft. of which 1, 86, 624 sq. ft. is conditioned space, excluding the central wings of the building. . The East and West Wings have been separated with a large central atrium to allow for wind tunnel effect. The entrance to respective wings are architecturally designed with large, transparent triple height glazing and interconnected on its 4th and 5th storey, with large bottom floor plate and relatively shrinking top floor plates as the building height rise. Among each wing are further two sub-wings B1 & B2 (on the West) and A1 & A2 (on the East) respectively. Each of them are separated to enhance day lighting into office zones along the respective façades. The occupancy pattern is fairly uniform across the buildings with estimated 2727 total occupants 1394 in Wings A1 & A2, 985 in Wings B1 & B2 and 348 for miscellaneous special areas. The observed working hour pattern approximately ranges between 8am to 9am and 6 to 7pm Indian Standard Time (IST).



Figure 1(a) External views of the SDB1



Figure 1 (b) spacing between wings

Site's Geography & Climate

Geography and climate play a lead role in the context of day lighting in built environments. Hyderabad is located in the central Indian state of Andhra Pradesh and is spread over an area of 260 km^2. The city lies in the Deccan Plateau and rises to an average height of 536 m above the sea level. The geographical coordinates of the city are 17.366° N latitude and 78.476° E longitude.

As per the Koppen climate classification, Hyderabad has a tropical wet and dry climate. The annual mean temperature is near to 26 °C, whereas the monthly mean temperatures range from 21–32 °C. The summer months are from March to June and are normally hot and humid. The average highs in these months reach mid-30°C and the maximum temperatures often exceed 40°C. Winter lasts for only about two to three months, during which the lowest temperature dips to 10 °C in December and January. May is the hottest month, when daily temperatures range from 26 to 38.8 °C. January, the coldest, has temperatures varying from 14.7 to 28.6 °C. Temperatures in the evenings and mornings are generally cooler because of the city's moderate elevation.

The sun path diagram for Hyderabad is shown in the Fig. 2. and Hyderabad experiences clear skies for most part of summer and winter and partly cloudy skies during monsoon. The design outdoor lux in India is taken as 8000 lux. With the given sky conditions, it is viable to capture good daylight for interior illumination. The detailed analysis of interior daylight distribution is discussed in sections to follow.

Lighting Guidelines

Green Rating for Integrated Habitat Assessment (GRIHA) is the national rating system of India. This help in assessing the performance of buildings against nationally acceptable benchmarks.

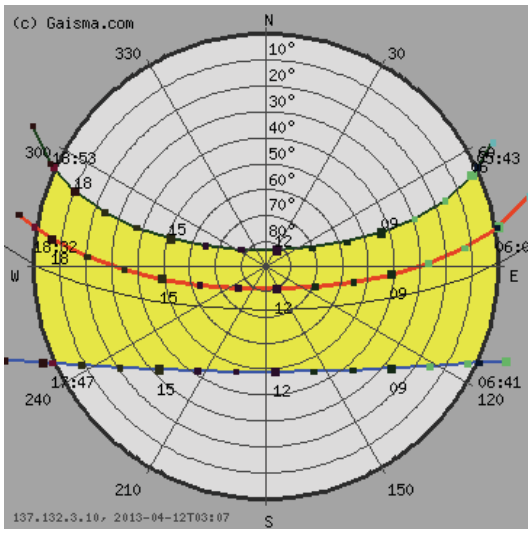


Figure 2 – Solar chart for Hyderabad

It evaluates the environmental performance of a building holistically over its entire life cycle, thereby providing a definitive standard for what constitutes a 'green building'. Different levels of certification (one, two, three, four and five stars) are awarded based on the percentage scored. GRIHA assesses a building out of 34 criteria and awards points on a scale of 100. In order to qualify for GRIHA certification, a project must achieve at least 50 points.

For lighting exclusively, SDB1 complies with criterion 13 under GRIHA rating system. According to this, it mandates:

- To limit the Window-to-Wall ratio (WWR) to a maximum of 60% and Skylight-Roof-ratio (SSR) to 5% of gross roof area.
- To comply with the Solar Heat Gain Coefficient (SHGC) requirement mentioned in Energy conservation building code (ECBC) for all fenestration.
- To ensure that at least 25% of the living area is day lit with the Daylight Factor (DF) of at least 1.9

Additionally every 25% increase in total day lit area shall fetch one additional point.

ANALYSIS

The analysis is carried out under two broad classifications – *Passive design* and *Active design.*

1. Passive design

This is a key building design aspect as it cuts recurring energy costs associated with artificial lighting. In this aspect, SDB1 is able to largely achieve the objectives with respect to day-lighting. The WWR is less than 30 % and SSR within 5% as per the GRIHA criterion.

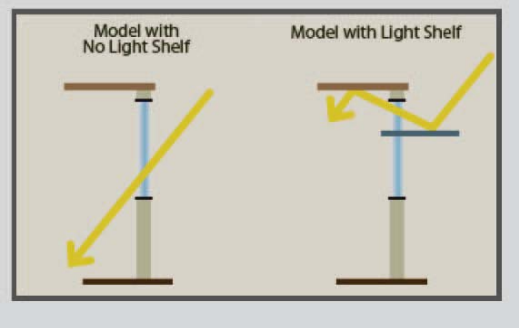


Figure 3 – Facade with & without light shelf

The Solar Heat Gain Coefficient (SGHC) requirements are also fulfilled using two separate window options – vision and daylight. The envelope design permits approximately 78% of the indoor space to achieve DF about 1.9. For office spaces, the GRIHA recommendation for DF is 1.9. Taking the outdoor design sky as 8000 lux and considering the sun-sky pattern over Hyderabad, the fact that attaining DF of 1.9 is not a challenge. Moreover, GRIHA rating does not require the interior space to be totally lit by day light alone. However, it is interesting to analyze to what extent does the daylight illuminates SDB1 when it comes to achieving the minimum task illumination levels.

Façade forming the envelope of the building is a critical aspect in passive day lighting. In order to harvest adequate amount of natural light, the glazed windows are split into two sections – lower vision and upper daylight pane. The upper pane lets in natural light and the lower pane provides the outside view as shown in Figure 3(right).

Light shelf is considered a simple yet potential passive day lighting enhancing technique in many commercial buildings especially office spaces. The surfaces of the overhangs of light shelves are reflective to allow the sunlight to bounce off these surfaces and onto the ceiling, which consequently reflects the sunlight deeper into the room.

In SDB1, light shelf is an element extending horizontally out from the façade and an equivalent or smaller element extends in to the interior as well. The external overhang being the most important element for day lighting, effectively doubles up as a shading device, preventing high angle solar radiation from entering the building. Light shelves offer improved daylight distribution, redirecting incoming light towards the ceiling and then back to the room and reducing the need for higher light levels especially up to few meters away from the window (Claros and Soler 2002). In addition, the internal surface finishes of the wall, floor and ceiling has reflectance values of 0.5, 0.2 and 0.7 respectively. The SHGC of the

selected glass for vision glazing for all orientations is 0.17

IES Simulation

To study the effectiveness of light shelves, simulations were performed using Integrated Environmental Simulation (IES) software with the following parameters (Table 1). The choice of simulation parameters is consistent with the field measurement.

Table 1 Parameters considered for IES simulation

PARAMETERS	VALUES
Sky illumination model	Clear sky
Work plane height	850 mm
Date	9th February
Time	13:00 and 16:00

Figure 4 illustrates the simulation results of temporal variation of daylight distribution contours at various points in the floor plate with light shelves across west wing B1 on ground floor of SDB1.

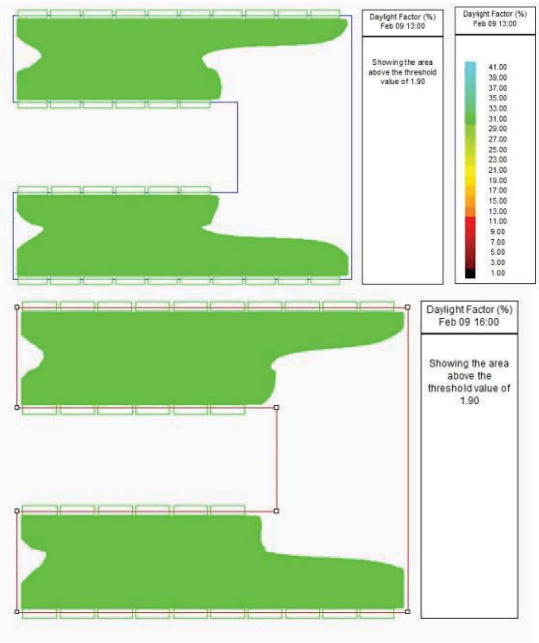


Figure 4 – IES Simulation output with light shelves at 13:00 (top) and 16:00 (bottom)

This is to determine whether there is sufficient daylight being permitted into the interiors of the office & then estimate the percentage of area lit-up for certain lux level (DF). The daylight factor is measured across full floor plate of 16m depth. Each point is measured concurrently with respect to the external point under the unobstructed sky to ensure consistency.

Figure 5 presents simulation results without light shelves for DF at 1.9 which indicates that only 52% of office area is illuminated as against 78.54% with light shelves.

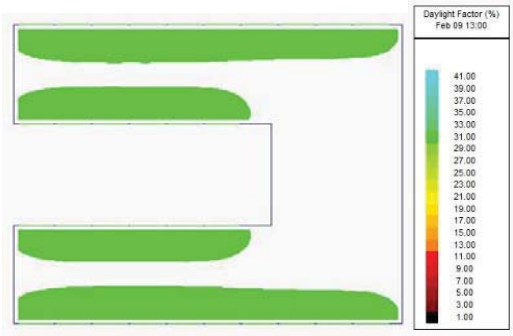


Figure 5 – Simulation output without light shelves at 13:00.

Figure 6 presents the simulation result of how DF varies along the floor plate. It is evident that DF of 1.9 is well distributed over 78% of the floor area.

With respect to the uniformity, which is defined as the ratio of minimum lux level to the average lux level in any given floor space, it is observed that the minimum lux level required is around 180 lux and the simulated average value received is 415 lux. This gives the uniformity to be 0.442, which is very close to the usual recommendation of 0.5

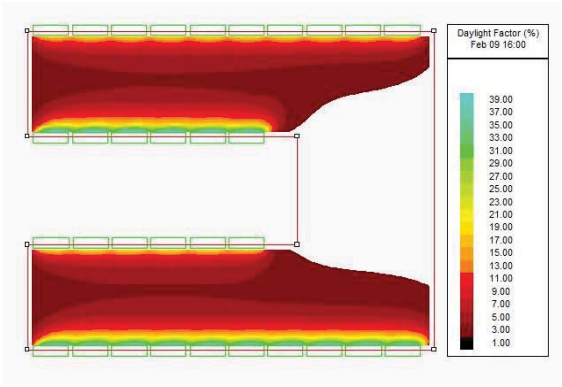


Figure 6 – Simulation output showing Daylight factor distribution.

Simulation results of depth of day light penetration into the office floor plate is presented in Fig.7 while the underlying details are discussed and analyzed in detail under field studies section to follow.

2. Active design

Active interior lighting design is important, but can be considered not as critical in a building which is typically used in the day – such as an office. Fig. 8 presents a snapshot of one such lighting floor plan.

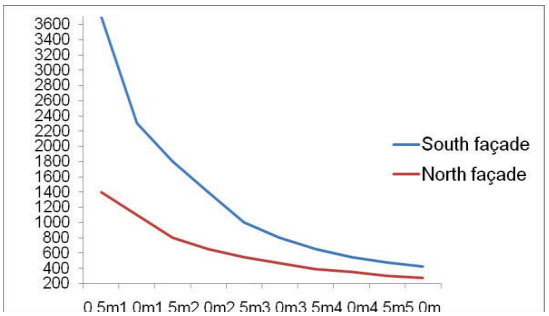


Figure 7 – Variation in daylight penetration depth along South & North facades



Figure 8 – Mixed office plan showing internal lighting layout of west wing B1 on ground floor.

The lighting system employed across the entire floor plan predominantly uses tubular fluorescent TL5 lamps. Use of TL5 lamps is directly relevant to energy efficiency and its saving contributes to the large share savings due to active lighting energy efficiency measures. The luminaries along with their higher efficacy, dimming characteristics & glare control features make them perfectly suitable for offices. The estimated potential energy savings attributed by choice of T5+electronic ballast choice over T8+magnetic ballast can be as high as 40-50 %.

A summary of type & number of fixtures installed in the mixed office plan showcased in Fig. 8 is presented in Table 2.

Table 2: Fixture type and corresponding loads

S No.	FIXTURE	QTY	WATT	TOTAL W
1.	Double – T5	261	64	16704
2.	Single – T5	66	32	2112
3.	LED	96	9	864

Lighting Power Density

The baseline standard for Lighting Power Density (LPD, in Watt/sq.ft.) for such office spaces according to GRIHA is 1.1 Watt/sq.ft. The proposed lighting load calculated for this building was 0.46 W/sq. ft. which is almost half of the baseline. The building is actually running at approximately 0.17 W/sq. ft. with sufficient daylight penetration combined by active day lighting controls, which is an excellent energy performance index. The tremendous energy savings was achieved using extremely energy efficient luminaries, controls and well-designed lighting layout with the help of pre-design simulations. Active strategies like daylight controls were designed to complement the passive design of the building.

LED vs T5

DIALux simulation enables photometric calculations in accordance with all important lighting standards and certificates. It estimates the energy consumed by various luminaires to achieve a particular task illumination level given the floor plate.

Figure 9 captures simulation output of DIALux for a comparative case analysis of T5 vs LED fixture of similar lumen output, in order to justify the right choice of fixture for the given area. The intent of this exercise was to evaluate performance based on choice of lighting fixture employed for the chosen office area. It was found that the T5 lamps achieved 0.46 W/ft2 compared to 0.59 W/ft2 for an equivalent LED based illuminance of 500 Lux. T5 bulbs perform at a source cost of approximately $3 per 1000 lumen, whereas the best comparison rival single LED bulb costs more than $70 per 1000 lumen. When a 4' linear T5 bulb burns out, it costs less than $3.00 to replace. Comparatively, it costs approximately $71 to replace a LED bulb.

FIELD STUDIES

The in-situ measurement followed the standard lumen grid method for interior lighting studies. Two spaces are covered under this. The B1 wing (refer fig.8) of Ground floor and the A1 & A2 wings of 3rd floor.

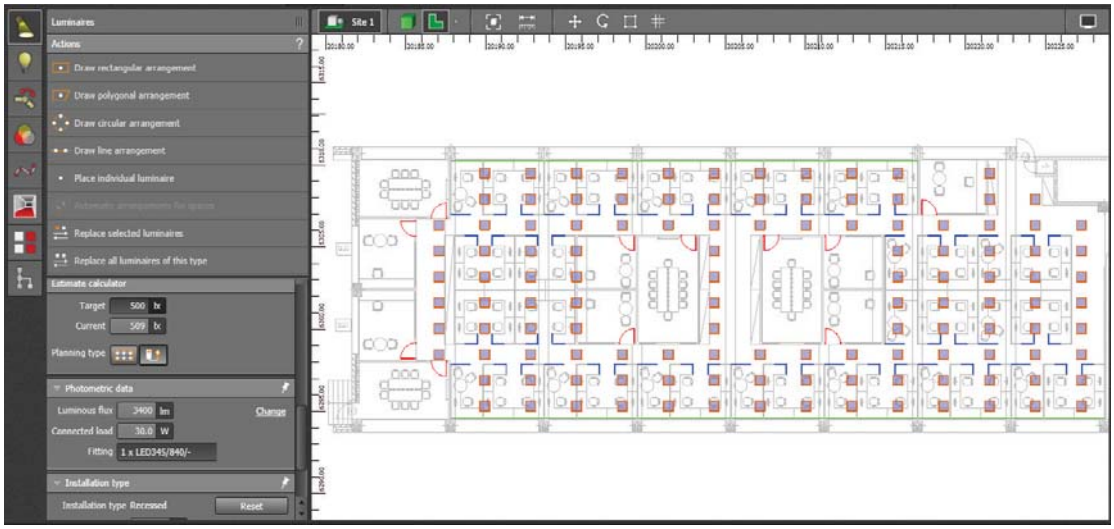


Figure 9 – Simulated LED fixture floor plan and lighting load estimate using DIALux

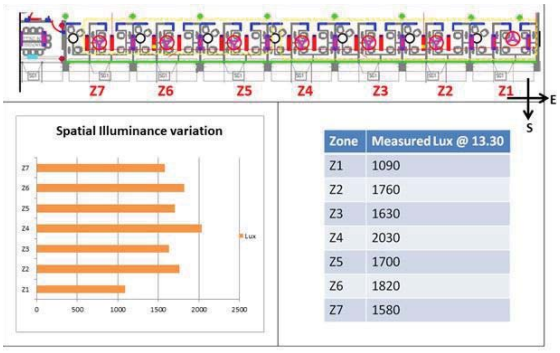
The measurement approaches are summarized below:

1. The entire floor plate is divided into virtual grid marked by the uniform distribution of ceiling mount lighting fixtures
2. This followed by labelling them into zones viz. Z1, Z2 & so on along the depth of daylight penetration ie. South-to-North.
3. Actual measurements were conducted 1m above the floor level and directly underneath the lighting fixture along the zones-Z using fairly accurate Photo sensor or Lux meter.
4. Care is taken that the measurements are conducted fairly at the same instant of timing so as to annul the effect of temporal day lighting variation.

Measurement of daylight penetration

The first look at the ground floor-B1 floor plate (refer Fig. 8) revealed that interior office layout is arranged uniformly well with long open office floor plan along the perimeter of South and North façades. This helps in extracting uniform, maximum daylight mileage while the central floor plate observes relatively low over the office working hours. This is because South-façade faces zero or no obstruction whatsoever to the clear sky unlike the North-façade, which is self-shadowed by, wing B2 façade of the same wing. A quick look at the floor plan snapshot of wing B1 (Refer Fig. 8) marks distinct 7 zones starting with Z1 on the East-end towards Z7 on the west-end as labelled in Fig. 10 & 11.

From Fig. 10, it is clear that south-perimeter offices receive lux levels ranging from slightly over 1000 to 2000. A low level of illumination is observed in only one zone (Z1) ostensibly due to an absence of light shelf in that zone.

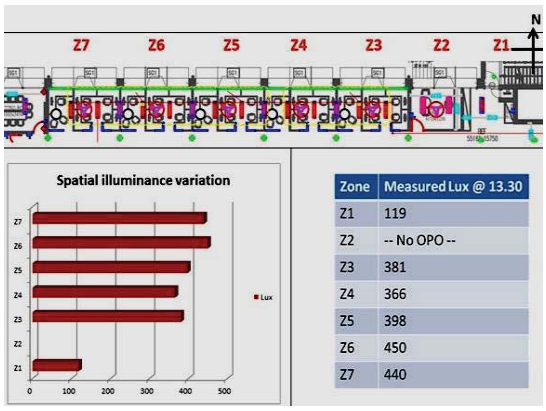


Zone	Measured Lux @ 13.30
Z1	1090
Z2	1760
Z3	1630
Z4	2030
Z5	1700
Z6	1820
Z7	1580

Figure 10 – South façade of open-plan-office with zonal labelling and illumination levels

The highest illumination is observed along the centre of the length of the floor plate at Z4. The second lowest is achieved towards the west-end of the floor plate due to the clear reason that is bounded on west-end by meeting room. Similarly, measurements are carried out for the north façade and a summary is presented in Fig. 11. The lower illumination levels are due to the self-shading experienced on this façade due to its other wing.

For the third floor wings A1 and A2, the lighting fixture layout is slightly different from B1-ground floor. Hence, our measurement methodology is also modified. We made use of the same grid-methodology but owing to the non-homogeneity in lighting fixture layout unlike in ground floor, we have our Lux measurement points modified to the centre of each open office cube on the work plane at an elevation of 1m above the ground. The summary of observations is presented in Fig.12.



Zone	Measured Lux @ 13.30
Z1	119
Z2	-- No OPO --
Z3	381
Z4	366
Z5	398
Z6	450
Z7	440

Figure 11 – North façade of open-plan-office with zonal labelling and illumination levels

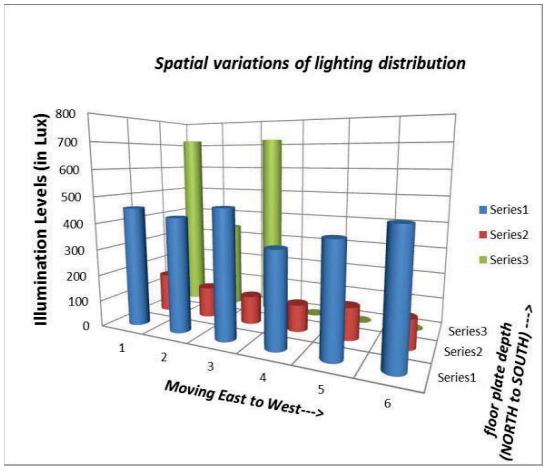


Figure 12 – 3D spatial chart presenting the measured lighting distribution in the 3rd floor-Wing-A2.

The entire floor plate of Wing A2, marks distinct 6 zones from West-end to far East-end. The day light levels received along North façade perimeter of the open-plan office is almost uniform, extending in the range from 350 to 475 Lux. Along the South façade perimeter open-plan office area it varies from 196 to 715 Lux. The reason for this trend is the obstruction presented by closed-office along one-end. The entire central bay receives almost light uniformly in the range of 102 to 151 Lux. Areas in the centre show less illumination owing to the fact that its ceiling presents lot of ducts running-along offering obstruction to light getting reflected from the ceiling.

KEY FINDINGS

- The orientation and layout of the building with reference to sun-sky pattern of Hyderabad is placed optimally with its longer axis along the East-West orientation.
- The simulated average illumination levels with light shelves for wing-B1 on ground floor is 415 lux with uniformity level of 0.442. This is well in range of recommended illumination level for such office space of 500 lux & 0.5 respectively.
- Simulations without light shelves for DF at 1.9 shows that only 52% of office area is illuminated as against 78.54% with light shelves.
- Simulations using DIALux show that the LPD obtained using LED (6.4W/m^2 or 0.59 W/sq. ft.) is similar to that obtained by the T5 lamps (6.5W/m^2 or 0.6 W/sq. ft.). Considering the cost effectiveness in the long run, T5 lamps are a better choice.
- The field measurements indicate that illuminance received on work plane along South perimeter due to day light is good (order of 1000 lux) whereas, along the North perimeter it is under 500 lux. This is because the South façade has almost zero obstruction to the sky through the glazing while North façade experiences self shadow of the building's adjacent wing. Having said that a lux level of 300 – 350 on work plane could be considered as sufficient for the type of work being carried out in the building.

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SUSTAINABILITY FOR BROILER SHEDS: AN AUSTRALIAN STUDY

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ABSTRACT

Globally, the economic benefits associated with food and nutrition are significant, with recent government reports indicating that the state of Victoria in Australia is responsible for the production of a third of the nation's poultry production.

The aim of this research is to examine practical changes that can be made to typical broiler facilities to enable energy efficient methods for broiler production. Broiler sheds largely rely on electricity to keep birds comfortable. As the facilities for broiler production have greater heating, cooling and ventilation requirements than those used for egg production, the paper focuses on these. The use of construction materials in the overall life of the facilities is also considered, however, embodied energy is not considered. This paper examines alternative scenarios to maximise bird productivity while exploring different options for heating, cooling and ventilation. The study demonstrates practical changes that can be made to broiler sheds in the Developing World.

INTRODUCTION

Food and nutrition are an essential part of daily life. Poultry meat has surpassed beef and veal production, and in 2005 poultry meat production was 20.6 times higher than ten years earlier. Likewise in Asia, both egg and poultry meat has risen 181% and 134% compared with 1990 levels (Daghir 2008). With the outbreak of bird flu in 1997, again in 2003/04 (WHO, 2011) and now recently in early 2013, questions around how livestock are housed and transported have become critical. In 2012, Australian poultry exports were 4-5% of total volume, and almost half of the exports were to Hong Kong (Eco News 2012).

This paper outlines the issues associated with the chicken livestock or broiler industry in Australia, with particular reference to the State of Victoria. 'A broiler farm is land used to keep large numbers of chickens that are housed permanently in sheds and reared for meat production. The type of chicken produced is called a broiler. Chickens are grown to specific processing weight in enclosed sheds, where they are free to roam the shed floor and where they have ready and continuous access to feed and water' (Department of Primary Industries (DPI) 2009). In this paper, the reference to poultry sheds, broiler sheds and chicken farms are spaces for growing chicken for human consumption.

Aim

The aim of this paper is to examine practical changes that can be made to typical broiler facilities to enable energy efficient methods for broiler production. Where possible, sustainability implications are considered. The paper examines the challenges and barriers to maximise bird productivity while exploring different options for cooling and ventilation in existing sheds. Embodied energy is not considered. One broiler farm was used as a case study to understand the greenhouse and financial implications of the changes suggested. Discussions with the peak industry body: the Victorian Farmers Federation (VFF) and some broiler farms in Victoria were also undertaken. The findings of the study have implications for not just broiler facilities, but similar types of sheds. These opportunities can be tapped in the Developing World where population increases will lead to greater demands for housing and food.

The paper commences with understanding the issue associated with broiler sheds from an environmental perspective, followed by an understanding of typical broiler houses. The sustainability considerations, including energy efficiency are examined, and opportunities for change are discussed. The paper ends with conclusions and recommendation, with inferences on what lies in the future.

ISSUES ASSOCIATED WITH BROILER SHEDS

Since broiler chickens are raised for human consumption, care needs to be taken for ensuring that the chickens are raised in a hygienic environment. For this reason, there are some basic hygienic issues to be considered: condition of the litter, the temperature and humidity levels in the broiler shed and associated to this, type/s of shed construction to ensure that the temperatures and humidity levels are suitable for raising chickens and, food and water for the chickens. The litter needs to be friable and in

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good condition for raising the birds. Humidity should be monitored too, as too much humidity will start caking the litter, and too little will make the air too dry. Waterlines should be of appropriate height for growing birds, and the quality of water should be good for birds. As birds are housed in sheds, ensuring comfortable temperatures is an important consideration. Wall, roofing and floor insulation (where appropriate) needs to be well thought through, as well as ensuring a good moisture barrier. Fans are needed for ventilation and foggers (spraying fine mist of water) are often used as cooling systems in broiler sheds. In Victoria, ventilating the sheds in summer is not so much an issue as it is ventilating them in winter. Incorrect ventilation not only affects the condition of the birds, it also affects the condition of the litter.

Currently, in practice ideal temperatures for brooding in Victoria as determined by the growers are 24.0-26.5^{0}C and this is ideal for birds at 3.5 weeks. For hover brooders, it may be as high as 35^{0}C. In winter the temperature may be up to 36.7^{0}C and in summer it may be as low as 33.3^{0}C. By 28 days when the birds are big, their own body heat will keep them warm, hence by the time they are ready to be culled at 6-8 weeks, the temperatures fall further from 25^{0}C to 18-20^{0}C. Due to their place in the supply chain, growers are better able to respond quickly to assist in getting best outcomes for the processing companies, unlike government departments.

Silos for bird feeding, water tanks for water storage and use, and standby generation for ensuring that there is an option in the case of an emergency all need to be considered, hence in Victoria, they exist as farms. It is important for birds to eat and drink on their own, so the light intensity needs to be well balanced. It does not bode well for the birds to be hyperactive, nor should they be lethargic.

State of play

In terms of sustainability issues associated with broiler sheds, existing uses of power sources and general conditions internally within the sheds have been the focus of various studies. For example, a study has been undertaken about poultry litter as a source of power in the UK (CADDETT 1995). In an example of its use at Eye in the UK, 12.7 MW of electricity was generated, enough to power 13,000 homes annually. Around 130,000 tonnes of litter were used annually. Electricity was exported to the grid. Also, in the UK, a recent study showed that for a 2000 sq m south facing roof, it is possible to provide more than half (55%) of annual electricity use in the broiler farm, mainly for heating and ventilating the poultry sheds (Clarke 2011). In the US, too, there are opportunities of using Photo Voltaics (PVs) for high-energy end users such as broiler farms (Morley 2003).

In Australia, as part of the Poultry CRC, research is currently being undertaken to incorporate bentonite and other 'smart sorbers' (synthetic clays) into litter, so as to improve the fertiliser value of the material from the outset. Laboratory volatilisation trials have indicated that bentonite as a bedding material, combined with spent wood shaving-based litter, decreases ammonia volatilisation relative to the spent litter alone and may (if applied in-shed) improve air quality and bird productivity (Poultry CRC 2006-13).

Czarick and Fairchild (2013) have documented the design requirements for poultry sheds in hot climates. In the past, Australia has undertaken research on how farm buildings should be designed, particularly from a functional perspective (Agricultural Engineering Society 1976). However, no recent studies on the design of broiler sheds in Australia are documented.

Rodić et al (2011) show that compared to other livestock, poultry is quite environmentally friendly, largely due to very efficient feed conversation, high daily weight gain, and lower emission of methane. William et al (2006), by undertaking a life cycle assessment (LCA) show that free range and organic poultry production are more environmentally harmful than intensive production systems. A recent study in Australia presented the cradle to gate (restaurant) life cycle assessment (LCA) of chicken production for a major poultry producer in Australia. The study found that upstream feed production (the food used for feeding the chooks) is the largest impact area of the broiler supply chain, contributing to two thirds of the overall water consumed. Farm operations contribute to a third of the overall impact; largely the manure emissions and energy used in the production houses (Bengtsson and Seddon 2013).

Emissions associated with livestock

The quality of air in and around the broiler farms or any livestock is a key focus for ensuring the health of the environment, livestock and humans. If livestock health is affected, humans tending the livestock are also affected. Hence, livestock health makes not just financial sense but also protects the human health while working with livestock. There are obvious emissions to the environment when considering livestock. These emissions also contain contaminants: gases, odour, airborne particles and noise and affect animals, plants and humans. Effects on the environment are largely through ammonia emissions affecting vegetation, soil, surface and ground water production.

A study reported by Chinivasagam et al (2009) showed that public health risk from organisms such as salmonella, campylobacter and escherichia coli via aerosols in poultry environments are very minimal. In another study (Sanz 2012), it was found that in surroundings of a poultry farm in the UK, the

ammonia fingerprints was quite low. In Spain, the ammonia concentration decreased to levels of 3-5 μg/m3 (background levels for the area) within distances of less than 600 m, whereas at the same distances around a broiler farm the concentration levels were double.

In a study in South Australia (Banhazi et al 2007) it was found that four factors were considered to have significant effects on the concentrations of airborne particles and management or features of different broiler buildings. These were cleaning between batches of birds, biological loading of sheds, ventilation levels and humidity. Manipulating humidity, temperature, ventilation rates and biological loading of the sheds for dust reduction purposes may prove to be difficult, as these factors are also related to thermal comfort and economical performance of the birds.

Chicken health is affected when exposed to high levels of dust, ammonia, hydrogen sulphide and carbon dioxide (ICAG 1994). High levels of ventilation are therefore, required. Other gases of note are hydrogen cyanide and carbon monoxide, both of which are toxic to humans and animals. Humans can develop hypersensitivity, pneumonitis, chronic bronchitis, cute inflammation, occupational asthma and toxin fever (ICAG 1994, p. 14).

The use of plenum flooring in broiler sheds seek to reduce ammonia levels by 80% or more, reduce energy use by 10%, improve feed conversion by at least 4%, reduce dust and particulate material by 30% and increase retention of nitrogen in the manure in lieu of emission (Ritz 2011). However, this is not yet used in practice in Victoria.

Ventilation, temperature and lighting

As indicated in the previous section, ventilation is a major requirement for poultry housing. Ventilation is required for ensuring that the CO_2 and ammonia within the sheds do not reach levels harmful to the birds. Ventilation is also essential to ensure that internal temperatures and humidity can be reduced in very hot weather. Air movement needs to occur at the bird level to reduce the temperature amongst the flock and to help keep the litter dry and in friable condition. Fans are used, particularly in hot weather. Size of fans, accuracy of the control systems, provisions of fail-safe mechanisms and alternative sources of power of providing air all need to be considered. Careful design of inlet and outlets is essential.

The ambient temperatures in broiler houses need attention. Geographical areas, latitude, altitude, shelter and prevailing winds are significant elements. Cooling may be considered through ventilation. Solar heat gains may be considered through evaluating insulation, roof colour and pitch, orientation, shelter and shade. Again, cooling the roof with water may be considered where appropriate.

Optimum light levels in broiler houses should be such that light is not dim. Brighter light can be used to stimulate activity. Birds feed depending on light conditions; a balance between hyperactivity and lethargy needs to be maintained. Light levels should allow birds to see and be seen clearly. Levels of illuminance suggested are 20 lux throughout the house at bird eye height, with 10 lux as the minimum. During inspections, lighting levels needs to be at least 200 lux (FAWC 1992).

PRODUCTION HOUSES FOR BROILERS

In Australia, as in the UK, and US, the broiler industry commenced in the 1960s. The production houses or broiler houses are where chickens are grown to an age of five to eight weeks, after which they are collected for processing. Some chickens may be removed earlier than eight weeks, but once all the chickens are removed, litter bedding is also removed, sheds are cleaned and disinfected and fresh litter is applied. This ensures that the sheds are hygienic. Each grower may rear an average of approximately five and a half batches in a year.

The growers rear chickens on behalf of the processing companies for a fee. The processing company delivers the day old chicks, provides feed and medication as required. They may also provide management advice throughout the growing period. When the birds are ready during the five to eight weeks, the processing companies cart them to the slaughterhouses. The growers provide infrastructure, and the labour to rear the chickens.

Chickens are usually housed in timber or steel framed, well-insulated, windowless buildings with concrete floors and a controlled environment. Broiler chickens are always reared loose-housed on deep litter floors, with no cages (cages now seen in Europe) or wire floors used. The floor is covered with bedding materials made of white wood shavings or rice hull. Provision of food and water has become increasingly mechanised over time. It is common to find the provision of heat in the chick stage.

Among the many changes to production methods over time (FAWC 1992) is the recognition that the environment for housing chickens is now controlled with greater precision. There is some focus on free-range broilers, and less intensive indoor systems, although this is still a minor part of the Victorian and Australian industries. It is easy to understand that in a conventional broiler, the levels of control are much higher than that of a less intensive indoor production system or a conventional system.

In a study by Chinivasagam (2012), it was found that by examining the physical parameters (pH, moisture content, water activity, and litter temperature) as a means of understanding Salmonella dynamics in the litter environment, there was a trend for lower levels of Salmonella diversity in the re-used litter environment as compared to the new litter environment. This may be due to the lower water activity associated with the re-used litter.

It was found through another study (Atzeni et al 2011) that the odour in broiler sheds is particularly high when human activity in the shed increases, as it does during the late-afternoon feed schedules, due to more stable atmospheric activities during this time.

Broiler houses in Victoria

The Victorian Code for Broiler (DPI 2013, 2009) provides a basis for the planning, design, assessment, approval, construction, operation and management of broiler farms in Victoria. It was first set out in 2001 when it was incorporated into the Victoria Planning Provisions and all planning schemes in Victoria under the Planning and Environment Act 1987 and updated further in 2009 (DPI 2013). This updated code was incorporated into the Victoria Planning Provisions at the same time. The code is used for new broiler facilities and those seeking to expand broiler facilities and seeks to present an appropriate balance between the operational needs of the broiler farm industry and the protection of the environment, particularly the air environment for people who live near broiler farms. While there are environmental issues addressed in the planning and design of broiler farms, the standards are by no means stringent and there are opportunities to push the boundaries for ensuring that some sustainability requirements are also met.

In 1987 there were predominantly 4 broiler producers in Victoria (Brown 1987). In 2003, these numbers increased to 6 processors and 220 farms, with sales of $650 million growing annually at 4% per year. Victoria represents about a third of the nation's chicken production. Currently across Australia, there are two large integrated companies supplying 80% of broiler chickens marketed in Australia (VFF 2013, Poultry CRC 2013).

Due to increased concerns from the community, local, state and federal government, Victorian processors and growers have recognised the need to physically improve environmental, safety and other performance areas and, secondly, to openly involve government agencies and active community citizens in prioritising and implementing the improvements so that results achieved meet everyone's needs (Smith 2003). The focus for best practice identified from the consultation with the industry in 2001-02 was on using best practice drinkers, equipment and litter monitoring; removing litter immediately from the farms; ensuring care and timeliness of feed delivery and bird pick-ups and matters pertaining to training, legal and quality assurance matters. While these issues are important, the actual design and planning of sheds, quality of the indoor environment, health of growers and reductions in energy use of the farms were not considered. Some of these issues have been considered in the 2009 update to the code, however, in comparison to other measures introduced by the Federal government for energy efficiency, these have a long way to go.

In Victoria, the first broiler house or sheds were built in a variety of ways such as timber frames with asbestos cement sheet or corrugated iron external cladding and later moving to cement sheet lining with spray foam insulation. Many of these sheds are still in production but reaching end of life and presenting problems with disposal of asbestos and insulation. Figure 1 is an example of an early style shed.



Figure 1 Typical early style Victorian Broiler shed (cross flow), Source: Agricultural Automation

Most sheds are situated in semi-rural or rural areas zoned as farms with the placement density value of 21.5 birds/m^2. This is representative of a typical industry placement density. As birds are removed at intervals for processing, density is reduced. Based on the numbers of birds kept on the farm, the ability to contain the separation distance with the broiler farm boundary and proximity to other existing and proposed broiler farms varies.

Today, sheds are typically built with steel and concrete. The typical shed houses forty to fifty thousand birds and is around fifteen metres wide and one hundred and forty metres long. Class A and B broiler farms may have up to 400,000 birds. Victorian broiler houses have a steel frame, a concrete wall to around six hundred millimetres high and a 50 mm thick sandwich panel wall from the concrete to the eaves. This wall is usually built with two sheets of steel with polystyrene insulation in between. The roof is usually corrugated iron or 'colourbond' with fibreglass insulation blanket and 'canvacon' (a polyethylene based product) lining or more recently sandwich panel similar to the walls. The floor is usually constructed from low permeability materials such as concrete, compacted

clay or any other sealed surface. It needs to be above the natural surface level to prevent the entry of storm water run-off. Or, the shed may be bunded, or a surface drainage system installed to prevent the entry of storm water run off. Figure 2 shows an example of a typical modern Victorian shed with tunnel ventilation, where ventilation is along the length of the shed using fans.



Figure 2 Typical Modern Victorian Broiler shed (Tunnel Vent), Source: Agricultural Automation

Farms today may start with four or five such sheds and expand over subsequent years. In addition, such sheds may be added to older farms or replace sheds nearing the end of life. Investors are also moving into the industry and building very large farms with ten or more sheds.

Generally, buildings and works are designed and constructed to minimise their visual impact. On flat land, vegetation to screen the buildings is encouraged. Sheds are orientated to minimise the risk of odour, dust and noise impacts on the surrounding buildings with tunnel ventilation fans located at the furthermost point away from the nearest sensitive use, such as a house. The design and construction facilitates the efficient delivery of feeds and birds, collection of birds, and the cleaning and maintenance of sheds and collection areas. Broiler sheds and feed silos are constructed to ensure that they are protected from wild birds, vermin and rodents.

Feeding and watering systems are critical. Continuous water supply needs to be available for drinking, shed cooling and shed wash down. Back-up supply or storage of water is needed. Feed and water systems need to be adjusted to the height of the birds as they grow. Feed systems and silos need to be designed, sited and constructed to minimise the spills of feed.

The equipment used in the sheds consists of fans, heaters, lights, vents, feeders, drinkers, pumps and winches. An electronic programmable environment controller operates the heating, cooling and ventilation equipment automatically.

There is a high peak in demand for electricity during the summer months for cooling and ventilation. This is achieved by using fans to draw air in through a wet wall and extract it out the other end of the shed at a speed of around three metres per second.

In the past, lighting was most commonly provided by approximately one hundred incandescent light globes burning for up to eighteen hours a day for around forty-five weeks of the year. These are now illegal and are being replaced with a combination of halogen and fluorescent lights.

Other electrical equipment does not contribute significantly to overall energy usage, however it may produce peaks in usage, which may increase the rate charged under certain billing regimes by utility providers.

Environmental issues pertaining to broiler farms are usually associated with run off of nutrients or waste to the surrounding environment. This may be into ground and surface waters, particularly into waterways. Main wastes associated with broiler farms are spent litter, dead birds and general farm waste, including chemicals most of which is currently removed from the farm.

Having discussed the typical shed, the next section will discuss opportunities to make them sustainable.

PUSHING THE BOUNDARIES

A number of new technologies or new uses for existing technologies are becoming available now that point in the direction of a more sustainable shed. Some technologies are already being adopted in other industries but are new to the poultry industries in Australia. For example, imrpoved insulation in the roof to reduce heating costs, walls with higher R values and use of plenum floors. Plenum floors reduce ammonia emissions and improve indoor air quality. In pushing the boundaries for sustainability, calculations were undertaken for a broiler farm with five sheds and discussions undertaken with the Victorian Farmers Federation and some farmers to understand whether they would be prepared to make suggested changes .

Longevity and recyclability

There seems little on the horizon to replace the steel and concrete materials, as the steel frame is essential for the necessary spans as are the concrete walls to withstand the wear and tear of machinery operating inside. Both are essential for longevity. Longevity or durability does improve the sustainability of the sheds as most sheds will remain in production for as long as they are structurally sound giving good value from an embodied energy perspective. At the end of building life, the shed can be dismantled and recycled, except may be the walls due to hygiene issues.

The walls (and in some cases, the roof) of these sheds may still pose recyclability issues in that the

sandwich panel is not easily recyclable, as the polystyrene insulation is not easily separated from the steel skins, but may be recycled if separated. As the sheds are expected to last fifty to eighty years, little disposal will be needed for the next fifty or more years, so in terms of the embodied energy the longevity of the sheds is a distinct advantage. *Spanlift* (2013) is a company marketing these types of poultry buildings, having high thermal ratings in the walls, ammonia resistant lining with all steel members assisting with recyclability. While the value and need for insulation is well understood, however, unless the sheds themselves need to be changed, there is very little incentive for farmers to move to using new materials for building new sheds.

Ventilation

Ventilation and cooling are the most significant contributors to electricity usage. Electronically Commutated (EC) fans may reduce upto 28 tonnes of CO_2 emissions per annum (EBM Papst 2013). EBM Papst (2013) develop EC fans that assist in ensuring not only reduced energy consumption, but also provides a longer life cycle; hence, a better value from an embodied perspective. All parts are steel, particularly stainless steel with some parts optionally aluminium, all of which can all be recycled. To put this into practice however is difficult as technological capabilities will vary from farmer to farmer and training may be required. The latter also requires financial outlay and resources which is scarce for farmers. Generally, speaking however, the value of using fans is well understood..

Lighting

Traditional incandescent or halogen light globes can be replaced with LED lighting. This gives benefits in energy savings, greenhouse gas emissions, and long term use of the lights. Increased longevity reduces the amount of globes that end up in landfill each year. Replacing incandescent lighting with LEDs can save a further 32 tonnes of CO_2 emissions for a single farm, shown in Table 1.

Although initially more expensive than current lighting systems, LEDs offer very short payback periods. LED lighting also overcomes problems with the ability to dim halogen and fluorescent globes and so provides a better outcome from a management perspective. This is possibly the easiest change to convince the industry to adopt, driven in part by legislation. Products in the market place such as Agrilamp are claiming an energy saving of 95% compared to incadescent lighting (Agrilamp 2013) supporting recent reseach that poultry do well under LED lights (Mendes et al 2013). Supported by Agrifund to assist farmers in the UK by providing funding, this product has the potential to make lasting energy savings not just in the UK, but also Asia and Australia. One Victorian farmer claimed to be running the whole shed on LED for less than the cost of one incandescent light globe.

Solar energy

Poultry sheds have large roof area that may be utilised for production of solar energy and the greatest demands for power coincide with the best conditions for producing solar energy.

For the shed considered in this paper, using solar energy with diesel boosting as a back up can save 46.7 tonnes of CO_2 emissions per annum, as shown in Table 2. There are challenges on sizing the system however, due to the big peak in summer demand where a combined solar/grid solution seems most practical at present. It is possible that farms may be able to become fully independent and not rely on the grid for any use of energy.

Additional benefits arise from use of solar power in conjunction with grid electricity is that peaks and troughs are levelled out. Reducing peaks under current billing regimes reduces further, the rates paid for the entire period. The impact of this is reduced peaks felt by the grid generators. Perceptions of long paybacks however, still persist amongst farmers. Intial investment is another drawback, as is the perception of the efficacy of using solar technology. To convert existing sheds to become generators of solar energy, the weight of solar panels on the roof also need to be considered.

Challenges and drivers

The most powerful driver of change for this industry is cost reduction. The most influential industry participants are unlikely to be driven by ideology. The major businesses are privately owned and not subject to the same scrutiny as public companies. The industry's current business model can limit farmers' access to capital. There are few processors for whom a farmer can grow chickens that puts the farmer in the position of price taker. Most poultry sheds are owned by individuals and very small businesses. Processors hatch and own the chickens and pay farmers a growing fee for the venue and care until the chickens are returned for processing. Individual farmers have little influence. As cost of utilites increase, the drive to make change become necessary.

As in the case of most sectors, corporate social responsibility is a minor dirver. The farmers debt level is also an influence, those with low levels of debt are better placed, however these are more likely to be a dwindling number of 2nd generation farmers.

CONCLUSIONS AND RECOMMENDATIONS

At present there is more scope to improve the sustainability of poultry sheds by introducing energy

efficient equipment and improving the overall design of the sheds, than there is in changing the materials used in construction. This is where the low hanging fruit is as the technologies available now represent real dollar savings as well as environmental benefits.

Change that does not offer a financial benefit is unlikely to be implemented by farmers alone, as they struggle with up front costs. It may, however, be possible for processors and governments to work together to consider change from an industry wide perspective and look for models that offer long term benefits to the industry and the environment. The replacement of electricity from the grid with solar energy is now simple and more cost effective with reduced payback periods and offer a substantial contribution to reducing CO_2 emissions. Energy efficient equipment significantly reduces the size, and hence cost, of the solar power generation system required. Likewise, using recycled water for cooling and for poultry feed may also assist in reducing resource use, and is therefore a positive step in the direction of sustainability.

While it is essential that commercial and residential buildings are targeted for energy efficiency, it does not mean that other types of buildings such as broiler sheds cannot also contribute to energy efficiency and make inroads in the move to become sustainable. Development of new technologies can be adapted to other types of buildings such as sheds and broiler sheds. By examining the case study of Victoria, Australia, there are lessons that the broiler houses of the Asian region can learn, in preparation for increased urban growth in the short to medium term.

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Table 1
Lighting energy savings calculator

Lighting Energy Saving Calculator					ANL Lighting	
Number of Lamps	100			Days per week open	7.00	
		Hours/day	18.00			
Energy Rate $	0.15			Weeks closed /year	4.00	
	CURRENT		HALOGEN		COMPACT FLOURESCENT	LED
Lamp Wattage	60		35.00		15.00	7
(watts)						
Lamp Life	1000		3000.00		6,000.00	30000
(continous hours)						
Cost of lamp $	2		5.00		8.00	50
Maintenance cost	25		25.00		25.00	25
($/Hr)						
Replacement Time	3		5.00		5.00	5
per lamp(mins)						
No.i times replaced	30		10.00		5.00	0
Actual life span	8.6		25.70		51.40	257.2
(weeks)						
Lamps relaced per year	606		202.20		101.40	20.2
Lamp cost per year $	1213.2		1101.00		808.00	1011
Maintenance cost per year $	758.25		421.25		210.62	42.13
Electricity cost per year $	5459.4		3184.70		1,364.90	636.93
Initial outlay $			708.33		1,030.00	5208.3
Yearly Cost	$7,430.90		4616.90		2,384.30	1690.1
Yearly Saving			2813.00		5,046.60	5740.8
Payback time			13.09		10.39	47.18
(weeks)						
Greenhouse gas, emissions			21231.00		9,099.00	4246.2
(kg CO_2 per day)	36,363.96					
Greenhouse gas, Saving (Kg CO2 per day)			15165.00		27,297.00	32,150
Black ballon saving			303300.00		545,940.00	643000

Table 2
Savings using Photo Voltaic panels

Power/System Analysis Form

YOUR DETAILS: Name:	M Sweetnam			
Site Address: Bittern-Dromana Rd Dromana Vic 3936				
Phone:		Email:		
Electricity Bill/Qtr:		10000.00	Per Annum:	$40,000
Power costs in 2 years allowing for 25% increase:			Per Annum:	$50,000
Cost of Power Peak/Shoulder	$0.20	$0.20	Average	$0.20
Average Daily Usage kWh	544.7			
Estimated daylight hours usage	50%	Power used in daylight hours kWh		272.33
	Cost of power consumed in daylight hours			$20,000
System Details				
Inverter				Fronious
Inverter model				IG PLUS 150
Inverter warranty (yrs)				10
PV Panel				TrinaSmart
PV Panel power rating (Watts)				250
Number of Panels				100
Kilowatts				25.000
Aspect Efficiency %				100.00
Hardware Costs				51,824.00
Standard Install				15,000.00
Metering				TBA
Tigo Management System				
High Works, crane, access, etc.				
Kliploc roof clamps				
Install roof mount kit @ $70/tilt				
TOTAL VALUE				$66,824.00
Less Rebate				$13,320.00
INVESTMENT				$53,504.00
Systems potential per year*				$8,991.05
Daily Production Potential in kWh				120.75
Total Savings per annum				$8,991.05
Investment realisation yrs				$5.95
Annual Depreciation 5% pa				2,675.20
Investment realisation yrs after Depreciation				4.59
R.O.I per annum**				16.80%
Average Daily Production in kWh*				120.80
% of your daylght hours usage				44.30%
Annual CO2 savings (Tons):				46.72
Lifetime Savings (30 yrs)***				$1,018,534
Rebates are calculated at: $30.00 per STC and are subject to change				

Notes. Metering for labour only. The meter remains the property of your Energy Provider
Where time of day meters are in place, electricity cost for daytime use calculated at average of peak and shoulder rates
**based on saving electricity at the rate of $0.204 excluding GST. All prices within this sheet exclude GST*
***return On Investment calculated at current power cost and will increase with each price rise*

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SLUM UPGRADING AS A CONTRIBUTION TO A MORE SUSTAINABLE CITY

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ABSTRACT

The aim of the present article is to seek to demonstrate how slum upgrading has contributed to making cities in developing countries more sustainable. To do this we analysed the real experiences encountered in some of Brazil's largest metropolitan areas (São Paulo, Salvador of Bahia, Rio de Janeiro and Belo Horizonte), using urban sustainability parameters and guidelines. The research employed post-occupancy evaluation method with a view to gauging user satisfaction levels.

We hope that the following article will help cities to improve their urban and housing management approaches particularly with a view to ensuring more sustainable urban environments.

INTRODUCTION

Cities have long been viewed as problematic areas from the environmental point of view, given that they continue to attract increasingly large numbers of inhabitants, thus generating negative impacts on the natural environment. This negative situation can basically be traced to the following: (a) an increase in land occupation resulting from the phenomenon of urban sprawl; (b) the use of natural materials to build cities, such as sand, stone, timber, concrete and steel; (c) the consumption of energy and materials to sustain the operation of the cities; and (d) the production of wastes such as greenhouse gases, garbage and sewage.

In developing countries, the above are compounded by rapid city growth and by the shortage of resources needed to manage this situation. Informal settlements have tended to mushroom as a result, frequently as a direct outcome of urban planning deficiencies. Areas that are undervalued and rejected by the real estate market or those that are unsuitable for building, such as areas at risk from flooding and landslides, end up being occupied by low-income segments of the population with insufficient funds to rent or purchase a minimally habitable property. (Davis, 2006)

Cities have thus become the scenarios for two very different co-existing realities: on the one hand, the 'formal' city conforming to legal guidelines and enjoying standard urban infrastructure and services, and on the other, the 'informal' city built by the residents themselves in precarious areas with no access to infrastructure, services or shops, and which is often not even acknowledged as being part of the city proper. (Huchzermeyer, 2004)

For many years public policies focused on efforts to eradicate slums and transfer their populations to social housing complexes. Given the need to render social housing financially viable, the units were often located in low-cost areas increasingly remote from the city centres and where services, shopping facilities and transport were in short supply. (Werna et al., 2004)

These policies were doomed to failure since many of the relocated residents in such buildings were dissatisfied and in many cases abandoned their new homes to move back to slum areas closer to the city centre. A further disadvantage of the outlying social housing estates was that the public authorities were forced to employ their scarce resources to supply infrastructure and a range of services - including transport to ensure access to such places. In view of the failure of these relocation policies local governments gradually came to accept that the most effective solution for resolving the housing shortage problem, as well as the negative environmental impacts caused by informal settlements, would be to upgrade these settlements. (Cities Alliance, 2010)

DISCUSSION AND RESULTS OBTAINED

The term "slum upgrading" is open to broad interpretation. It can be applied to any intervention in an urban settlement that results in the improved quality of life of its inhabitants. Slum upgrading can range from the installation of basic infrastructure and improvements to streets, access-ways and upgrading dwelling units, to providing basic services such as garbage collection, health and education amenities. In recent years new items have been incorporated into the slum upgrading programs such as environmental education, land tenure regularisation, income generation and suppressing crime and lawlessness. The slum upgrading process in Brazil has grown and evolved as governments and technical staffs have succeeded in accumulating experience of upgrading informal yet highly complex settlements. (Brasil, 2007)

Four programs have been developed in the main Metropolitan Regions of Brazil as follows. (Abiko and Coelho, 2009)

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Figure 1 São Paulo

In the case of the Metropolitan Area of São Paulo (Figure 1), the Guarapiranga program aimed principally to recover and improve the quality of water supplied from the various springs around the city. This water was contaminated by the enormous amount of sewage flowing into the reservoir from the slum areas built on its banks. In order to undertake the environmental recovery of the water catchment area it was necessary to develop a multidisciplinary approach to deal with the various problems caused by water contamination and sewage disposal, by constructing adequate infrastructure for the existing slum areas around the reservoir.



Figure 2 Salvador of Bahia

In Salvador of Bahia, the Ribeira Azul program (Figure 2) was also targeted principally at improving the environmental and sanitary quality of the water of the Baía de Todos os Santos, which is the recipient of a vast number of rogue drainage and sewage systems, many of which originate in the slums located around the bay. The program embraces a number of different actions including infrastructure and environmental recovery works, the construction of new houses, human development projects, etc.

In Rio de Janeiro (Figure 3), in the 1990s, it was estimated that around 1200 informal settlements occupied approximately 10% of the built-up of the city and was home to roughly 1.4 million people. The urban situation was even more precarious given that only between 25% and 30% of the informal settlements benefited from normal urban infrastructure services such as sewerage networks, drinking water, public lighting or regular garbage collection. The Favela-Bairro program aimed to transform the slums into conventional city neighbourhoods by installing sanitary and drainage infrastructure and ensuring that the access routes and streets of the informal settlements were connected to ordinary neighbouring areas, with a view to ending the relative isolation of the slum settlements and integrating them properly into the conventional urban fabric of the city.



Figure 3 Rio de Janeiro

In Belo Horizonte (Figure 4), the program aimed to construct housing units and improve existing ones. The priority in that city was to deal with truly precarious and insalubrious risk areas occupied by families with the very lowest incomes.



Figure 4 Belo Horizonte

The slum upgrading programs, in addition to providing minimum living conditions, also conform to a set of guidelines which inter-alia include many of the urban sustainability guidelines publicised by movements such as New Urbanism and Smart Growth. (Cities Alliance, 2010)

These guidelines aim to address some of the following (Magalhães and Villarosa, 2012):

- Integrate the settlement's transport system with the existing system and with local or nearby links/streets/ sidewalks;
- Promote the landscape potential near to the project for recreation and leisure;
- Eliminate risk areas with slope stabilization and drainage structures;
- Provide a new water and sewer infrastructure and ensure that both are connected to the public network;
- Design an environmental preservation system to conserve or recuperate native vegetation through reforestation with native species;
- Conserve water bodies and wetlands by planting with native species to avoid new informal settlements;
- Treat watercourses and design a sediment and erosion control plan;
- Avoid land movement;
- Provide services and equipments close to the project in order to satisfy local demand for services;
- Maintain stormwater volume and water pollution rates. Provide adequate drainage for developed areas in order to minimize pollution outcomes of watercourses;
- Avoid urban sprawl;
- Work directly with community associations and/or other social community networks. Advertise public meetings aimed at generating public comment on project design;
- Analysis undertaken of local and regional historical patterns of neighbourhood development and building design;
- Attention paid to drainage systems, transport facilities, water and sewer infrastructure and availability of natural sunlight;
- NBR 9050 - Brazilian regulation to accessibility;
- All dwellings to be supplied with energy;
- Promote economic activities among the local population compatible with environmental preservation.

CONCLUSION

In the four Slum Upgrading Programs it was possible to detect improvements in the quality of life both of the people living in the intervention area is as well as in the city as a whole, mainly in the cases of São Paulo and Salvador, where a significant environmental component was involved. Slum upgrading has softened negative environmental impacts with the installation of proper sewerage networks, and existing water bodies were freed from clandestine inflows of raw sewage. Moreover, the introduction of garbage collection services meant that rivers, streams and vacant lots ceased to be dumping-grounds for domestic waste generated by people living in the surrounding areas. Finally, with the efforts to improve street systems and shore up precarious slopes, the risk of landslides was considerably lower. A further advantage is that the electric power companies stand to benefit from fewer losses, generally caused by rogue connections.

It can be affirmed that slum upgrading has contributed to making Brazil´s cities more sustainable. However, much work remains to be done. Regardless of the immediate improvements flowing from the various programs what is needed is a policy designed to underpin and maintain the various interventions so that the systems, materials and solutions that have been deployed are absorbed by the resident populations of the intervened areas, so that local people are able to provide continuity to the programs without depending totally on the public authorities. In tandem with the engineering work, what is needed is to press ahead with social and community work aimed at enhancing the awareness of the beneficiaries of the interventions in their new capacity as members of the conventional, 'formal' city.

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ROLE OF EMBODIED ENERGY, OPERATIONAL ENERGY AND RELATED GREENHOUSE GAS EMISSIONS OF BUILDINGS IN THE CONTEXT OF DEVELOPING TROPICAL COUNTRIES

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ABSTRACT

Greenhouse gas (GHG) emissions from fossil energy sources are a major cause of climate change. Building sector is the single largest contributor to global emissions. However, the emission saving potential the sector possesses is substantial. In order to ensure sustainable development, the future building projects in the tropics should take a special look into the GHG-emissions of the buildings.

Traditionally, the research focus on buildings' energy use has focused on operational energy. As buildings, become more energy efficient, the role of materials increases in both relative and absolute terms. However, the past research on the topic has focused on developed and/or cold countries and only a few examples of developing tropical countries exist.

This research identifies six parameters, which need special focus when applying current research findings to developing tropical countries. These parameters are: the level of operational energy use, the transition from traditional to modern building materials, the role of insulation, the role of advanced building systems, the production technology of materials and the energy production methods and energy carriers.

INTRODUCTION

The research focus on building's energy use has been traditionally on the operational energy. (Sartori and Hestnes, 2007, Hernandez and Kenny, 2011). This approach has been well reasoned, since the operational energy use of buildings has dominated the lifetime energy use by contributing as much as 95% to the lifetime totals in the past (Sartori and Hestnes, 2007).

Even today, the operational energy use is often the single biggest contributor to the lifetime energy use of buildings. A recent overview of 73 cases by Ramesh et al. (2010), for example, looks into the previous life cycle energy analysis of buildings. The authors find that the role of embodied energy in building materials is at the level of 10-20%, while the role of operational energy use is at the level of 80-90% in the analysed cases. Similarly, Yung et al. (2013) find in their review of 206 cases that the embodied energy equals to 7.5 to 7.8 years use of operational energy. On a 50-year life cycle, this translates into 15-16% of totals.

Recent development in energy efficiency of buildings

The current development, for example, in the European Union, is towards more energy efficient buildings. As buildings, become more energy efficient, the role of materials increases in both relative and absolute terms. This means that the building materials will become even more important when targeting energy savings and emission reductions in the future. The underlying logic is that the low operational energy consumption is usually achieved by additional material use in insulation and more advanced building systems. A review of 60 cases by Sartori and Hestnes (2007), for example, observed that the embodied energy of low-energy buildings could account to almost 50% of the lifetime totals in extreme cases.

Ultimately, if the energy-efficiency of buildings reaches a "zero-energy"-level, with no operational energy consumption, the role of embodied energy will become crucial. If the operational energy level reaches zero, then all the lifetime energy consumption will be due to embodied energy, as Hernandez and Kenny (2011) point out.

According to the existing literature, increasing the energy efficiency of buildings appears to be a very effective way of decreasing the total lifetime energy use and the related emissions. However, this seems to hold only to a certain limit in some cases. Passive houses (a specific type of low-energy buildings), for example, may perform better in terms of life cycle energy use than similar, self-sufficient buildings (Sartori and Hestnes, 2007). This is due to that the excessive use of passive and active features in self-sufficient or zero-energy buildings may be counterproductive and low energy buildings may perform better in life cycle context (Ramesh et al., 2010).

In order to ensure energy efficiency over the whole life cycle of a building, the embodied energy needs specific attention, especially when designing highly energy-efficient buildings.

Research concerning developing, tropical countries

The past research concerning the role of building materials has focused on developed and/or cold countries and only a few examples of developing

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tropical countries exist. A look into the sources cited in the previous sections shows that all the 60 cases of Sartori and Hestnes (2007) focus on developed countries, only four out of the 206 cases of Yung et al. (2010) are on developing countries and six out of the 73 cases of Ramesh et al (2010) consider developing countries. Furthermore, even if the focus is almost solely on developed countries, it is still hard to draw universally applicable conclusion based on the existing research. This is due to that the assessed cases differ in terms of climate, country, type of building, type of construction, assumptions on indoor climate and source of data (Sartori and Hestnes, 2007).

Due to these factors, it is necessary to exercise extreme caution when applying the current research findings into developing and/or tropical countries. This paper looks into some specific parameters affecting the embodied energy, operational energy use and the related greenhouse gas emissions in developing tropical countries. The aim is to point out some of the most important parameters for future research.

RESEARCH METHDOD

This paper uses the well-established method of literature-based discovery, where existing literature is used in order to gain new knowledge. According to Swanson (2008), literature-based discovery (LBD) enables one to extract new knowledge from something already published. The opportunity to do so is brought up, when two different articles, when studied together, suggest information which is not evident from either one of those two articles, if studied alone. In that case, the articles are considered to have a complementary relationship, which is based on their scientific problems, findings and arguments.

The complementary relationship can also be extended from a pair of articles to a pair of article sets. In general, if two different article sets share a great number of articles, they are probably of low interest for LBD. (Swanson, 2008)

Based on the underlying logics of LBD, the existing review studies on the life cycle energy consumption of buildings and life cycle assessments are assumed to offer only a little interest for LBD, as they share a large amount of background data. Moreover, they focus on developed and/or cold countries, making conclusions on developing and tropical countries uncertain and difficult to draw.

As a result, the research approach selected for this paper is to take individual research findings from tropical, developing countries, and compare them with each other, and together with the existing body of literature. The assumption is that by this approach, new information on the developing tropical countries can be discovered.

This research uses the widely acknowledged Köppen-Geiger climate classification in determining the tropical regions (Peel and Finlayson, 2007) and classification by the IMF (2012) for determining the developing countries within such regions.

RESULTS AND DISCUSSION

This research identifies six parameters, which need special focus when applying current research findings to developing tropical countries. These parameters are:

- the level of operational energy use
- the transition from traditional to modern building materials
- the role of insulation
- the role of advanced building systems
- the production technology of materials
- the energy production methods and energy carriers.

Each of these parameters are explained in more detail in the following sections.

Level of operational energy use

The location and respective climate have a direct effect on the level of operational energy use, since majority of it comes from heating and cooling demand. The climatic conditions mainly affect the operational energy use, and have no significant effect on the embodied energy, as stated by Sartori and Hestnes (2007).

The most obvious difference between cold countries and tropical countries is that while cold countries need heating, the tropical countries need cooling. Ramesh et al. (2010) point out that the heating energy in cold countries is produced with varying energy sources, but the majority of cooling energy needed in the tropics is produced with electricity. This may lead to differences in primary energy use and greenhouse gas emissions, since electricity has typically higher impacts than other energy sources. The role of energy mixes will be discussed in more detail in a later chapter.

As Chiraratanon and Hien (2011) and Zhai and Previtali (2010) illustrate, the thermal comfort in tropical buildings in Thailand and Indonesia have traditionally been achieved by a combination of low thermal mass, good shading and natural ventilation, in both private houses and public buildings. In terms of ventilation, a combination of open doors, windows and gaps in the raised floor have allowed natural

ventilation in traditional buildings in the tropical countries (Chiraratanon and Hien, 2011).

The level of operational energy use is quite different in developed and developing countries. While developed countries aim towards zero-energy buildings through increased energy-efficiency, the starting point in the developing tropical countries is quite the opposite. As traditional tropical buildings only natural ventilation and only small amounts of other energy, the operational energy use is expected to rise in the developing countries, together with increasing disposable income. This has been the development, for example, in Thailand (Chirarattanon and Hien, 2011).

The tropical climate presents a different set of design conditions from those of cold countries. This section shows that the starting point for the research on developing tropical countries is quite different from the developed and cold countries. Whereas the developed countries have zero-energy as their goal, this might closer to the starting point in the developing countries. Thanks to increase in disposable income, more and more people in the developing tropical countries can afford to install air-conditioning, allowing a better indoor climate. However, from the viewpoint of energy and greenhouse gas emissions, this development will lead to more operational energy use and greenhouse gas emissions in the near future.

Transition from traditional to modern materials

The design of buildings and selection of building materials is changing in the developing countries due to various reasons, such as the level of disposable income. The change from traditional building materials into modern ones results in changes in both embodied energy and operational energy use. However, these changes are not completely straightforward, as this section highlights.

As Zhai and Previtali (2010) point out, the traditional buildings in Indonesia take the advantage of light structures with low thermal mass, which allow indoor climate to follow the cooling temperature of ambient air in the evenings. However, the shift from traditional building materials to modern ones seems to change this setting. The research by Chirarattanon and Hien (2011) state that there is a commonly held belief that massive walls perform better than light ones in air-conditioned buildings in the tropics. The authors show, however, that even if the walls with high thermal mass are able to delay transmission of heat into building interior, this reduces air-conditioning loads only during daytime. The effect in the evenings, on the other hand, is the opposite.

Utama and Gheewala (2008) find in their study of single landed houses in Indonesia that a shift from fired clay-based bricks to concrete blocks increases the air-conditioning need and operational energy use, leading to higher lifetime energy consumption. This is due to more beneficial thermal properties of clay bricks (density 950 kg/m^3, conductivity 0.27 W/m K, specific heat 840 kJ/kg K), compared to those of concrete blocks (density 1800 kg/m^3, conductivity 0.785 W/m K, specific heat 657 kJ/kg K).

A research by Ramesh et al. (2012a) also looks into the use of fired clay bricks and, interestingly, ends up with seemingly contradictory results. The authors state that fired clay bricks perform worse than modern materials, such as hollow concrete, soil cement, fly ash and aerated concrete bricks. However, the Indian bricks they analyse (density 1700 kg/m^3, conductivity 0.84 W/m K, specific heat 800 kJ/kg K) differ significantly from the Indonesian bricks discussed in the previous, explaining the result. As the authors sum up, a lower operational energy can be achieved by using building materials in the building envelope, which have a low thermal conductivity and a considerable heat capacity, at parity of all other conditions. If the embodied energy of such materials is low, that leads to lower life cycle energy use. (Ramesh et al. 2012a)

The cases analysed here suggest that in some of the developing tropical countries, the move from traditional materials to modern ones may result in increased embodied energy and operational energy use. Such is the case, for example, when traditional wood-constructed, naturally ventilated buildings are replaced with buildings made with concrete structures and air-conditioning. However, the case is the opposite, for example, if fired clay bricks are replaced with modern materials with lower embodied energy and better thermal performance.

Due to the issues presented here, it is not clear, how the shift from traditional building materials to modern ones will affect the embodied energy and operational energy use, if left unguided. However, it seems that increasing the use of materials with low embodied energy, thermal conductivity and a considerable heat capacity could result in lower operational energy use and the best life cycle solutions. It is suggested here that steering policies (both formal and informal) could assist in choosing the best materials for future buildings in developing tropical countries.

Role of insulation

As stated in the introductory chapter, increased insulation layers typically increase the embodied energy, but lower the lifetime energy use of buildings

through increased energy-efficiency. However, as this is found through case studies in developed and/or cold countries, this issue should be looked into in more detail in the developing tropical countries.

Chirarattanon et al. (2012) point out that the buildings in Thailand have widely adopted air-conditioning, but no insulation is currently used. The authors find that internal insulation is more effective in reducing heat gains than external insulation, and that it results in net energy savings in most of the cases. However, the authors also point out that the heat gains through single-glazed windows (U-value of 5.25 W m−2 K−1, solar heat gain coefficient of 0.828) can be so high that insulation actually increases the operational energy use by restricting the heat transfer out of a building in the evening.

A research by Ramesh et al. (2012b) shows that a combination of additional wall and roof insulation in residential buildings, together with installation of double glazed windows, can result in 30% savings in life cycle energy use in the tropical India. The authors also point out, similarly to the existing studies that even though these additions cause a slight increase in embodied energy, savings in operational energy use offset it. Additionally, Ramesh et al. (2012b) also evaluate that the roof insulation is more effective, in terms of life cycle energy savings than wall insulation, and approximate that optimal insulation thickness in tropical climate is some 100mm (EPS) for both walls and roofs.

The cases discussed here are only some examples but they indicate that increasing insulation thickness (up to a certain limit) leads to better life cycle energy performance also in tropical countries. Due to the lifetime energy savings, also greenhouse gas reductions can be expected from additional insulation. However, this section also points out that insulation cannot be studied in isolation from other building components (such as windows) as that might lead to unsound solutions. Practical guidelines for the design of buildings could be a way to assist in adopting the best solutions.

Role of advanced building systems

As stated earlier in this paper, the existing literature points out that excessive use of passive and active features in self-sufficient buildings can be counterproductive and that low energy buildings may perform better in life cycle context. This section looks into this topic from a tropical perspective.

A research by Ramesh et al. (2012b) compare the total life cycle energy use of a building with a wind turbine and different levels of photovoltaic electricity production. The authors find that the embodied energy rises as the power generation capacity of the building is increased. However, the authors also find that case with the highest photovoltaic production is also the one with the lowest life cycle energy use. In their case, the net zero building results in the lowest life cycle energy use, at least partly contradicting the existing literature on the topic.

As there is only a single case study assessed here, further research would be needed for conclusions that are more definitive. However, this section points out that zero-energy buildings in the tropics may perform better in terms of life cycle energy use than low-energy buildings, contradicting the view of existing literature. This section also indicates that zero-energy buildings could potentially provide a good way for lowering greenhouse gas emission from buildings in the developing tropical countries through lower life cycle energy consumption and on-site renewable energy production.

Production technology of materials

The embodied energy is strongly location dependent due to a number of factors. For example, the location effects the energy content of building materials through raw material quality, efficiency of production processes, energy carriers and generation processes, which vary from country to country (Ramesh et al. 2010, Dixit et al. 2010). This section takes a brief look into production processes of materials in tropical developing countries, by using a commonly used building material, fired clay brick as an example.

According to Venkatarna Reddy and Jagadish (2001), the production of bricks, steel and cement are the biggest contributors to the building sectors energy consumption in India. They conclude that in order to reduce embodied energy of buildings, either alternatives for these materials needs to be found, or these sectors need to initiate significant energy savings.

The fired clay brick walls are a commonly used building material in the external and internal walls in developing tropical countries. In Indonesia, for example, clay bricks are a common material of external walls of residential high-rise buildings (Utama and Gheewala, 2009). They have also been the most commonly used wall material in single landed houses, though the use of concrete blocks is getting more common (Utama and Gheewala, 2008). The clay bricks are also the predominant wall material in conventional houses in India (Ramesh et al., 2010), and in Brazil (Paulsen and Sposto 2013). The use of bricks is also common in the external and internal walls of office buildings in Thailand (Koforola and Gheewala, 2009). However, their role is diminishing as concrete blocks are becoming ever more common also in Thailand (Chirarattanon et al. 2012).

The research by Kofoworola and Gheewala (2009) compare the embodied energy of materials in Thailand to those of New Zealand. The authors find that despite of different methodologies and system boundaries, the figures between countries match each other quite closely. However, the embodied energy of bricks shows almost twice the embodied energy of those of New Zealand. Similarly, for Indonesia, Utama and Gheewala (2008) report that the embodied energy of Indonesian bricks is more than double than that of Australian bricks. The authors state that both Thai and Indonesian bricks are produced with inefficient kilns, resulting in big heat losses in the process. The results indicate that the introduction of modern production technology might assist in lowering the embodied energy.

Venkatarna Reddy and Jagadish (2001) show that some alternatives for traditional burnt clay-bricks may result in embodied energy savings. As the authors show, alternatives for traditional burnt clay bricks, such as hollow-concrete blocks, soil-cement blocks and steam cured mud blocks, can bring 35 to 75% savings in embodied energy. However, as this paper previously showed, the material selection may have impacts in the life cycle operational use of buildings. Nevertheless, as Ramesh et al. (2012b) show that in India, more efficient alternatives do exist, as they demonstrate replacing traditional fired clay bricks with hollow-concrete, soil-cement, fly ash, and aerated concrete bricks.

The developing tropical countries could achieve reduction in embodied energy of building materials, such as bricks, by improving the production processes. However, economic realities may restrict this development. Another option is to use alternative materials. As this section showed, well-performing alternatives for traditional fire clay bricks do exist and their use should be encouraged.

Energy production methods and energy carriers

The energy production methods and energy carriers have a fundamental impact on the primary energy use and the greenhouse gas emissions of material production and building operation. These are the critical factors ultimately deciding the greenhouse gas emissions from embodied energy and operational energy use. This section looks into this topic in more detail. The current focus on developed countries in the literature may not give the right impression of the situation in developing countries, due to differing energy production methods and energy carriers.

Ramesh et al. (2010) point out that nearly all of the case studies in the existing literature are from cold countries where the majority of the operational energy, i.e. heating energy is produced with oil and gas (with primary energy factor of 1.4), whereas the share of electricity is relatively small. The authors point out that situation in developing countries, such as Thailand and India is very different, since all of the operational energy use, i.e., for cooling, is from electricity, produced typically with fossil fuels (the authors use a primary energy factor of 3.4 in their research).

However, even if developing countries and emerging economies are commonly using fossil fuels, such as coal, in their energy mix, this is not the case in all developing countries. In tropical Brazil, for example, the situation is substantially different. A research by Paulsen and Sposto (2013) sums up some earlier research by BEN (2011) and Coltro et al. (2003) concerning energy production in Brazil. The authors point out that the electricity produced in Brazil is mainly renewable (some 86% of it), the primary energy factor for electricity is 1.6 and CO_2-emission factor some 65 grams per kWh. These figures are substantially different from those Ramesh et al. (2010) present for Thailand and India.

It should also be noted that not only developing countries use fossil fuels and coal for their energy production. As for an example, Australia has a very high share of fossil fuels in its fuel mix (some 95%, according to ABARES (2011). This results in a CO_2-emission factor of some 1051 grams per kWh, according to AIE (2013), which is a significantly higher figure than that of developing Brazil.

Even though this section looked only briefly on this issue through just a few countries, it clearly shows that a country-specific energy mix should always be considered in the studies, not generalizations based on a county's status as a 'developed' or 'developing' country. The energy mix plays a paramount role when assessing the greenhouse gas impacts from energy use. Therefore, using generalizations on energy production will not give accurate information on the greenhouse gas emissions.

CONCLUSION

This research identified six parameters, which need special focus when applying current research findings to developing tropical countries. These parameters were: the level of operational energy use, the transition from traditional to modern building materials, the role of insulation, the role of advanced building systems, the production technology of materials and the energy production methods and energy carriers.

The tropical climate presents a different set of design conditions from those of cold countries. The starting point for the research on developing tropical countries is quite different from the developed and

cold countries. Whereas the developed countries have zero-energy as their goal, this is closer to the starting point in the developing countries. Thanks to increase in disposable income, more and more people in the developing tropical countries can afford to install air-conditioning, allowing a better indoor climate. However, from the viewpoint of energy and greenhouse gas emissions, this development will lead to more operational energy use and greenhouse gas emissions in the near future.

The design of buildings and selection of building materials is changing in the developing countries due to various reasons, such as the level of disposable income. The change from traditional building materials into modern ones results in changes in both embodied energy and operational energy use. It seems that increasing the use of materials with low embodied energy, thermal conductivity and a considerable heat capacity could result in lower operational energy use and the best life cycle solutions. The use of steering policies (both formal and informal) could assist in choosing the best materials for future buildings in developing tropical countries.

Installing thermal insulation can bring better life cycle energy performance also in tropical countries. However, insulation cannot be studied in isolation from other building components (such as windows) as that might lead to unsound solutions. Practical guidelines and information for the builders could offer a way to assist in adopting the best solutions.

It seems that zero-energy buildings in the tropics may perform better in terms of life cycle energy use than low-energy buildings, contradicting the view of existing literature. The zero-energy buildings could potentially provide a way for lowering greenhouse gas emission from buildings in the developing tropical countries through lower life cycle energy consumption and on-site renewable energy production.

The developing tropical countries could achieve reductions in embodied energy of building materials, such as bricks, by improving production processes. However, economic realities may restrict this development. Another way is to shift to using well-performing alternatives for traditional building materials. Information on the best materials and their benefits should be actively spread to the builders in order to support such transition.

The energy production methods and energy carriers have a fundamental impact on the primary energy use and the greenhouse gas emissions of material production and building operation. These are the critical factors ultimately deciding the greenhouse gas emissions from embodied energy and operational energy use. A country-specific energy mix should always be used in life cycle studies, as generalizations on energy production will not give accurate information on the greenhouse gas emissions and may even lead to wrong conclusions.

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PLANNED HOUSING ENVIRONMENTS AND CHILDREN'S OUTDOOR PLAY IN SINGAPORE: ENHANCING CHILD-FRIENDLINESS

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ABSTRACT

Children's outdoor play and their quality contact with nature in and around their neighborhood are reportedly decreasing in cities. A wide range of cross-disciplinary literatures demonstrate that low levels of active outdoor play and contact with nature have significant negative impacts on children's mental, social, and physical health, as well as on their overall development and wellbeing. Existing literature also suggests that the quality of the physical elements of neighborhoods significantly affects children's outdoor play behavior. This means it is very important to consider the ways in which existing urban neighbourhoods and planners can enhance children's outdoor play and their quality contact with nature rather than neglect these elements of children's urban lives. In the context of Singapore, research on children's outdoor play and quality contact with nature in public housing settings is limited. In such a context, what is imperative, as a first stage, is to understand the nature of children's outdoor play and children's quality contact with natural elements in and around their neighborhoods.

This paper focuses on the outdoor play behavior of children (aged 7 to 14) in two selected housing areas, Tiong Bahru and Pungol Cove, in Singapore. It begins with reference to the Child Friendly City (CFC) initiatives and article 31(1) of the United Nations Convention on the Rights of the Child (UNCRC 1989), of which Singapore is a signatory. Through observational field survey, a structured questionnaire survey of children and their parents, and interviews with children, we collected data on children's outdoor play and their perspectives on their preferred places in their neighborhoods. The collected data from the field survey was analysed using simple statistical methods.

Children's outdoor play (COP) in terms of natural or unstructured play (such as climbing trees, making their own play equipment etc.) was reported as minimal in the two study area whereas the average time spent outdoors (TSO) was found to be only about 1 hour per day for all children. In both study areas children reported that they spent much more time indoors on screenplay than outdoor playtime. This was true for both school days and holidays. The study further interprets the reported behavioural findings with the physical elements of the selected housings. Such data can then help develop future planning to ensure that cities are more child-friendly.

INTRODUCTION

Article 31(1) of the United Nations Convention on the Rights of the Child (UNCRC) states that:

> "States Parties recognize the right of the child to rest and leisure, to engage in play and recreational activities appropriate to the age of the child and to participate freely in cultural life and the arts." (UNCRC, 1990).

Along with this unique treaty, ratified by 193 countries, a significant amount of academic literature demonstrates the importance of outdoor play for children's mental and physical well-being (Moore, 1986; Woolley, 2012). Unstructured and independent outdoor play and children's quality contact with nature is important for children's mental and physical health and for children's social and emotional wellbeing (Kellert, 2005; Gleeson and Sipe, 2006; Louv 2010). However, despite growing concern, children's outdoor play and their quality contact with nature in and around their urban neighborhood are alarmingly decreasing in cities. Studies conducted in different developed city contexts show that children's outdoor play and mobility within urban areas had reduced alarmingly over the few decades (Hillman and Adams, 1992; O'Brian, 2000). In England, for example, from 1971 to 1990, children's independent mobilty, in the form of walking and cycling to school, decreased from 80% to 9% (Hillman et al., 1990).

Moreover, lack of awareness about the importance of children's outdoor play prevails in practice among professional groups involved in making decisions for the places where children live (Freeman and Tranter, 2011). The fact that professionals work within their own framework poses a problem for rethinking urban environments for children (and all user groups), which requires input from many disciplines. For example, the fear of motorized traffic is widely criticized in different child-friendly-cites literature. However, in reality it is quite impossible, for only a single group of professionals, to rethink existing transportation systems of a particular urban area. Not not only transportation engineers deal with motorized transportation networks; planners, architects and policy makers, management authorities also play their respective roles. Given that such complexities exist, the ways in which existing urban neighbourhoods can enhance children's outdoor play and their quality contact with nature rather than neglect these elements of children's urban lives, is very much a contemporary concern. Specifically, in

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the rapidly urbanising Asian cities, where research data on such issues is limited, inter disciplinary research can contribute to bridging such gap by informing and addressing the issues involved.

Singapore, a signatory to the UNCRC (October 1995), is a unique city-state in the Asian context with a land area of less than 600 sqkm. With a young population (aged under 15) of 870, 240 (16.8% of total population 5.18 million, National Population and Talent Division, 2011), Singapore has strong legal, regulatory and institutional framework to 'protect' children's rights (Singapore Children's Society, 2005).

Planned housing, managed mostly by the Housing Development Board (HDB), characterises the residential living environment in Singapore where more than 80% of its residents live. HDB housing provides neighborhood parks, children's playgrounds, 'void decks' (semi-open ground floor space below the high-rises) and managed green spaces within them. Residents recognise the importance of these parks and open spaces regarding children's wellbeing. The existing outdoor green spaces offer opportunities for the child to explore and learn about nature, run and play safely without fear of traffic, provide chances to socialize with other children etc. (Yeun, 1996).

At the city level, the Singaporean government has recently taken several initiatives that focus on enhancing people's (including children's) interaction with nature. The Park Connector Network (PCN) project by National Parks Board (NParks) is such a project. The park connector project, first proposed in 1992, was targeted to develop 300 km of park connector in 30 years time to provide recreational amenities to people. Proposed common activities in the park connectors include: cycling, walking, jogging etc (Tanuwidjaja, 2011). The project is being implemented now. Development of tha Kallang River Basin that prioritizes children's accessibility to river water and to other natural and imaginative features is another initiative at the city level (Joshi et al., 2011). The focus group report on sustainability and identity (URA, 2011) for the Concept Plan 2011 suggests injecting 'green values and habits' among the younger generations; and to include local communities in managing their environment. The report also suggests 'tree planting campaigns' to enhance the sense of ownership of the environment (2011:17). These are well-supported and suggested planning measures by various child friendly cities literatures conditional upon children being included and given the opportunity to participate in the process.

Despite comendable initiatives by the government, a trend of decreased use of outdoor places by residents and children is apparent in various studies in Singapore. In the mid 1990s, almost 50% of the respondents used neighborhood parks (NP) on a regular basis (Yeun, 1996) whereas the usage level decreased to 16.3% in 2008 (HDB, 2008). Along with decreased use of the outdoors, children's limited affinity for and interaction with nature is also a raising concern (Kong, 2000).

Given such a context, this paper tries to understand the nature of children's outdoor play and their interaction with outdoor natural elements in the planned housing environments in Singapore. Two study areas in Singapore: Tiong Bahru (Blk 1-82) and Punggol Cove (Blk 101-105), were selected for the study (Figure 1). We considered different but comparable neighborhood characteristics such as age of the town, traffic pattern, novelty value, building types, density and availability of outdoor play spaces etc.

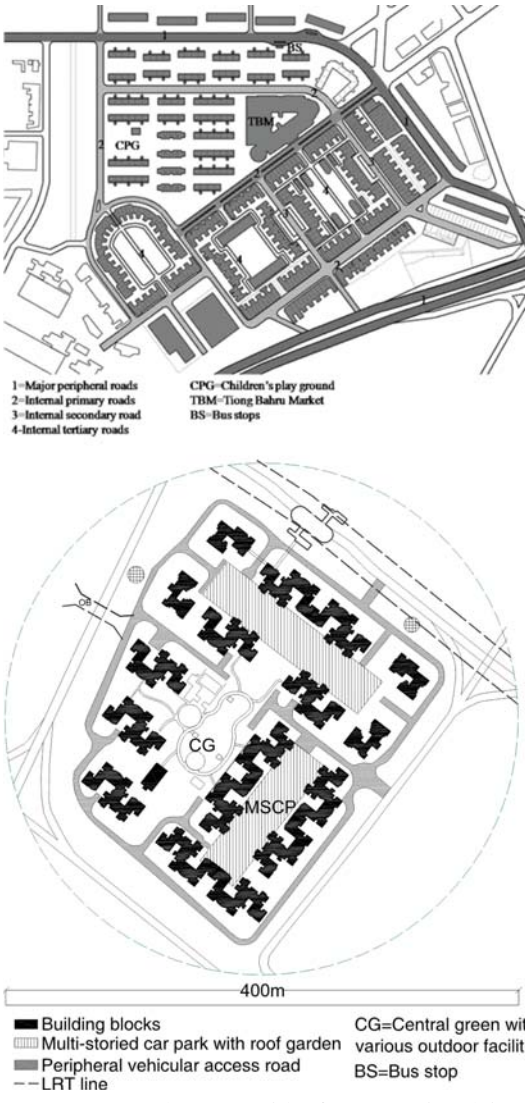


Figure 1: Map (not to scale) of Tiong Bahru (above) and Punggol Cove showing road networks and major outdoor facilities (Map redrawn based on URA Maps and Onemap.sg)

Tiong Bahru, an estate under Tanjong Pagar Town Council, is the site of some of the earliest public housing in Singapore, designed in the 1960s by the Singapore Improvement Trust (SIT). Tiong Bahru is characterised as a low rise, low-density housing with distinctive art deco style building types. Tiong Bahru is an estate with a highest density of elderly household, with many people having lived there since the estate was established.. The estate is close to the central part of the city. There are vehicular through roads within the area. Children from most of the blocks have to cross a vehicular road to have access to the only children's playground available. There exists a variety of land uses and facilities within this area. Unlike Tiong Bahru, Punggol Cove is a comparatively new development designed and built in the 1990s. It is characterised by high-rise and high-density areas with central common greens and peripheral vehicular access. Children can easily walk to the central common green and play areas using the void decks or shaded walkways at the ground level without crossing a vehicular road. Compared to Tiong Bahru, Punggol Cove has less mixed-use facilities inside the precinct.

While selecting the age group of children, we considered children's outdoor 'roaming' behavior (O'Brien et al., 2000), capacity to understand some logic for real objects, (Piaget et al., 1967) and the local context of Singapore where children usually move from primary to secondary schools at the age of 12. Singaporean children and their parents, who reside in the selected study areas, were eligible to take part in the study. Guided by such criteria, we included children aged 7 to 14 in our study.

METHODOLOGICAL CONSIDERATIONS

Lynch (1977) provides a comprehensive guideline and methodological instructions for studying children and their urban physical environment widely used later by other researchers (for example- Chawla, 2002, Islam, 2008). Influenced by Lynch, we followed a mixed method approach involving an observational survey, questionnaire survey and interview procedure to collect effective data that best suited the objectives of the study. We also took an area-based approach to emphasize the 'place' specific built environmental issues (Whitzman, 2009: 38). In the specific context, while developing the methodological framework and instruments of data collection, we had to take into consideration several related constraints such as overcoming the difficulties regarding approval from relevant authorities, difficulties involved in surveying children and conducting a survey in a relatively new context among others.

Getting Approval from Authorities

Our initial plan was to conduct a survey with children based in the local schools. However, we faced several institutional problems. In December 2011, we decided to source primary data and participants from the nearby schools in the selected research areas. We prepared the required documents such as our research proposal and objectives, invitation letters to the parents, invitation letters to the institutions or schools, a participant information sheet and consent form, a parental information sheet and consent form, data collection forms and procedures, sample size calculation; and possible survey schedule. Five months after submitting these documents for approval to the Ministry of Education (MOE) and NUS institutional Review Board (NUS-IRB), we received notice form the MOE that they would not give permission for us to work in schools. Considering our time related constraints, we formulated an alternative plan to collect primary data and recruit participants from inside the selected study areas. The major objectives and rationale of the study remained same in the new plan whereas we revised the data collection instruments and adjusted these to the new plan. NUS-IRB approved the revised submission and we started collecting primary data based on the approved research framework in July 2012.

Questioning and Interviewing Children

Questioning and interviewing children in real settings is both fun and challenging. It has to be 'ethical, sensitive and respectful' (Skelton, 2008: 23) as well as interesting to draw and maintain children's attention. In Singapore, English is the primary medium of education at primary and secondary level. Consequently as English speakers, (although one of us has Bengali as a first language) we were able to conduct the survey and interviews in English. We designed the children's questionnaire in a child friendly fashion by using short phrases and words composed with illustrated cartoons. This helped to capture the attention of the younger children. Children responded positively throughout the survey and seemed to enjoy being asked for their opinions and experiences.

Conducting Survey in a New Context

Being familiar with the places and the people of the study and involving local partners is important in research involving children's environments and mobility (O'Brien et al., 2000). As the case study settings of the study were relatively new to us, we took several measures to overcome this constraint. The first author, along with studying contextual literature, frequently visited and walked-through several (5-7) public housing areas in Singapore and attended meetings and discussions on similar topics with professionals, representatives of different authorities and sought their opinions and suggestions. Such activities helped us gain an introductory understanding about the people and the social context of housing environments in Singapore. As part of direct assistance, we involved a local Singaporean as a research assistant during the questionnaire survey

with good communication skills to engage with participants and communicate with them effectively.

FIELD SURVEY AND DATA COLLECTION

Followed by a comprehensive literature review and secondary data collection through desktop research, we collected primary data through fieldwork. Methods include an observational field survey; a questionnaire survey of children and their parents; and the one to one interviews with children.

Observational Survey

Observational surveys are widely used along with other associated methods in children's physical environment and behavior studies (Castonguay et al., 2010). This study used an observational field survey primarily to have a general idea about the pattern of the activities that people and children usually do outdoors. The other objectives were to be familiar with the places and facilities available within the areas. This is also known as participant observation. The first author visited the two selected study areas several times (7 to 8 times each) from December 2011 to July 2012. The observational survey was conducted as a time line survey. Charts and maps were prepared before the site visit. Various aspects of the built environment were recorded on site for the two areas. These were car frequency, number of users observed; and activity types etc. The author walked through the streets; sat for a while (ranging from 10 to 90 minutes) in the public spaces such as streets, play grounds, bus stops, food courts, roof gardens (at Punggol Cove); and observed activities of people focusing on children and their environment. We made notes on sketch book and on maps, and completed space activity charts. Visits were made at different times of the day and night on both week days and weekends. Photographs of the outdoor spaces were taken during the visits.

Questionnaire Survey and Interview

In investigating children's mobility and outdoor play self-reported questionnaire surveys were widely used (O'Brien et al.,2001). For the recruitment of participants, based on the experience of the previous reconnaissance survey, we (authors, and later a Singaporean research assistant) identified possible locations for approaching participants within the two study areas. The survey period was July 2012. We recruited participants primarily from the public spaces such as children's playgrounds, food courts and, in some cases, from the apartments of the study areas. At Tiong Bahru, the central food court and the children's park were identified as most suitable places for subject recruitment whereas at Punggol Cove, the key areas were the central green space with play facilities, void decks and the nearest food facilities across the road outside the site. Parents with children (aged 7-14) were verbally requested to participate in the survey. If they agreed, along with answers to any of their inquiries, participant and parental information sheets were supplied to the participants. The information sheets contained brief information about the project and its objectives, eligibility for the participants to take part in the research, the role of the participants, measures for the protection of the privacy of the participants, principal investigators contact address etc. Easy-words and short sentences were used in the participant information sheet for children. Written consent was taken from the parents to take part in the survey and also to allow their children to take part in the survey and interviews. Participants could choose to complete the questionnaires instantly to allow us to collect the completed questionnaires in situ. Alternatively, a convenient time (within 2-7 days) was set so that we could collect the completed questionnaires from the participants' home.

The one-to-one, semi-structured interviews with children were conducted by the the first author at a convenient time indicated during the questionnaire survey completion by the participants. Some of the interviews were conducted on the same day after the completion of survey questionnaire session with children. Places for interviews were the child's neighborhood playgrounds, food courts or their houses.

Survey Questionnaire for Children

The children's questionnaire was intended to collect self-reported data on children's outdoor play behavior. The questionnaire was an adapted version from Islam (2009) which was revised considering the local context, the objectives of this study and potential incorporation of measurable indicators. The questionnaire for children contained 15 open ended and closed questions. A range of questions involved children's leisure activities, outdoor play behaviors, preferences for outdoor play and mobility, highest distances of independent mobility, preferences for unstructured or natural play, liked and disliked places in the housing area etc. Social and demographic information such as age, place of residence etc. were gathered at the start of the questionnaire survey and were recorded in the separate data collection sheet. Table 1 shows the group distribution of the child participants.

Table 1: Group distribution of the child participants

Area	Gender		Age group		Total
	Boys	Girls	7-11	12-14	
Tiong Bahru	12	5	10	7	17
Punggol Cove	18	10	23	5	28
Total	30	15	33	12	45

Survey Questionnaire for Parents

The parent's questionnaire and the unstructured interview inquired about topics such as his/her child's activities during leisure time, outdoor play behavior during school days and school holidays, places where their child played outdoor games. Some of the questions inquired about parents' satisfaction with their children's play behavior, about how far parents usually allow their child to move on their own without assistance (parental license). We also sought their opinions regarding COP, friendly housing and 'play friendliness' and CIM friendliness of the housing area where they lived, and 'facilities' that may contribute in increasing COP in the neighborhood. In total, 18 parents took part in the questionnaire survey from both the areas. Unstructured discussion with the parents regarding the issue followed the questionnaire survey. Parent's responses were useful in understanding the issues such as intergenerational perspectives, parental license and residents' views on play friendly housing etc.

Interviews with Children

Gaining insight into how children relate their opinions and experiences (already answered during the questionnaire survey) to their surrounding environments, was one of the main reasons to include children's interviews in the study process. It is also important to ensure that children's voices are part of research about their actual play. Consent from children for their taking part in the interview were asked at the end of the questionnaire survey. If agreed, in most of the cases the interview was conducted instantly after the questionnaire survey. Due to time constraints, only a few interviews were conducted later at mutually suitable times. The interview guideline was prepared before the interviews were conducted. Most of the interviews took 15 to 20 minutes and discussed the key themes of the study.

FINDINGS AND DISCUSSION

We discuss the findings from the field survey questionnaires and interviews on children's outdoor play (COP) by grouping them into several themes and categories for further analysis. COP was conceptualized primarily in terms of unstructured or natural play; children's time spent outdoors (TSO) and children's independent mobility (CIM). We present and discuss the findings comparatively in terms of three variables: age group (children aged 7-11 and children aged 12-14), gender (boys and girls) and place (Tiong Bahru and Punggol Cove).

Children's Presence in the Outdoors

Children's presence in the outdoors of the neighborhoods, as observed during field observations, was very time specific. We found a small fraction of community children using the neighborhood parks only in the afternoon in both the areas. We saw children playing in the afternoon at the designated children's play areas and in the shaded void decks (at Punggol Cove). Almost no groups of children were involved in playing in the streets and other places such as inter-building green areas, pedestrian paths, corridors etc. In the morning (at around 6:30 am to 8 am) and at noon (2pm to 3 pm), children, singly, in groups and assisted by adults, use the pedestrian paths and the shaded pathways to go to, and come back from, school respectively.

Use of Outdoor Places by Children

Children, in both the study areas, had a limited interaction with the available open spaces. At the children's playground in Tiong Bahru the number of child users (on an average 30-40 children mostly assisted by adults) were fewer compared to the number of child users (50-60 children, both assisted and independent) observed on an hourly basis in the playground at Punggol Cove. In Tiong Bahru there is only one children's play ground with commercial play equipment; and that is not spatially connected with other facilities such as a jogging track, sitting pavilions, common green areas and fitness club, as it is in Punggol. Few houses are within children's pedestrian range (i.e. without vehicular crossings) of the children's playground in Tiong Bahru, whereas in Punggol, the common green play area is within pedestrian range for the whole precinct.

However, children's playgrounds on top of the roofs (roof gardens) of the multi-storied car parks (MSCP) in Punggol Cove were almost without children using them, although these playgrounds were much closer to the children's houses than the common green areas on the ground level. Physical factors for low presence in those roof gardens might be lack of co-presence of related-facilities. In Punggol Cove, rooftop playgrounds have fewer connections, both spatially and visually, to other available facilities than playgrounds and green spaces at the ground level.

Natural and Unstructured Outdoor Play

Children in both the areas reported few unstructured and natural play activities. We asked child participants whether they had: any experiences of climbing a tree in their neighbourhood; planted any trees or plants in their neighbourhood; changed something in their neighbourhood; played with self-made things (such as a kite, bat, paper plane etc.); and whether they did other similar things. Only 10% of all the surveyed children mentioned that they had ever climbed a tree or planted any tree or plant in their neighborhood. Almost all children reported that they had never made any change to anything in their neighborhood (Table 2). The majority of the children (62% boys and 60% girls) reported that they do not have any experience of the mentioned natural or unstructured play types. Only a few children reported experience of having one (23%) or two (13%) of the mentioned choices. No children had experienced all the four given play types (Table 3). This reinforces

Kong's (1999) assertion that Singaporean children have less contact with nature and as a result has less affinity and care for nature.

Table 2: Reported types of unstructured outdoor play (UOP)

Given choices for UOP	Percentage
Climbed a tree in their neighborhood	10
Planted any tree/plant in their neighborhood	10
Changed something in their neighborhood	3
Played with something that they had made on their own	26
Others	6

However, some of the children reported different kinds of unstructured play beyond the options provided in the questionnaire. For example, a 13-year-old girl at Tiong Bahru made a lantern on her own and played with it. Another 12-year-old boy at Punggol remembers that once he threw his shoes up on the roof of the shaded pathway while playing with them. It was a kind of different 'fun' to him since, after that event he had to devise many creative ways to get them down.

Table 3: Reported unstructured outdoor play (UOP)

	Total (%)	Boys (%)	Girls (%)
No experience of UOP	**60**	**62**	**60**
Experienced 1 of the given UOP option	23	19	40
Experienced 2 of the given UOP option	14	14	0
Experienced 3 of the given UOP option	3	5	0
Experienced 4 of the given UOP option	0	0	0

Wen et al. (2009) explain the continual decline in children's unstructured play and the concurrent increase in organized play, in terms of parents' concern for safety associated with unstructured play. In our study, it seemed to us, that a common fear of 'danger' and concern for 'safety' prevails in parents' minds when it is about climbing trees and other kinds of independent activities in green spaces. Some parents, who were present with their children during the children's questionnaire survey, expressed their concern that climbing trees or changing something in the neighborhood is not 'safe' enough. Although in the designed play grounds, children have equipment that involves climbing and riding high, it is perceived to be 'safer' compared to other kinds of natural play. This points to the need for further study regarding the sense of safety among the parents in this context. We did not find significant difference in the nature of children's unstructured play in the two selected study areas, apart from how little there was. However, boys selected more unstructured play choices than girls. Almost 40% of the boys took part in more than one unstructured play types whereas no girl reported more than one type.

Leisure Time

Children in earlier studies were reported to play outdoors within their neighborhood usually after school hours or during their leisure times as a kind of habitual activity (Moore, 1986). In our studied context, we adopted a similar notion of 'outdoor play' as a leisure or recreational activity. Reported average leisure time for all children was 2.68 hours per day. During schooldays, reported leisure time was less compared to school holidays, just as might be expected. Children aged 7 - 11 reported having less leisure time compared to the older age groups (2.3 and 3.67 hrs per day respectively). Boys enjoy almost 0.8 hours more leisure time per day than girls do. However, differences in the reported leisure time between the two study areas (0.46 hrs per day) were not as significant as the gender (0.81 hrs per day) and age group differences (1.37 hrs per day). However, there were significant variations, in term of the amount of leisure time reported by children, even of the same age groups, gender and within the same area. For example: A 13 year old boy at Tiong Bahru had a recorded leisure time of 7.5 hrs per day whereas many younger children from both the areas reported that they did not have their 'own' leisure time. We partially, for 16 cases, matched the leisure time data reported by children with the data obtained from parent's questionnaires. The majority of the children reported that they liked to watch TV (89.29%) along with playing with friends (78.57%); playing outdoor games (71.43%); play computer games (60.71); eating outside (60.7%); and reading books (60%) during their leisure time. Differences in the preference of outdoor play between boys and girls exist. Boys reported 'playing outdoors and playing with friends' more whereas girls mostly preferred listening to music and reading books.

Outdoor Time

The average outdoor playtime reported by the children was 1.1 hrs per day during school days (Table 4). This result of TSO is less than earlier reported TSO, i.e. 3.24 hrs per day, in the context of Singapore in 2009 (Dirani et al., 2009). Boys spend more average time outdoors (1.23 hrs/day) than girls. Unlike leisure time, younger children reported more time outdoors than older ones. In Punggol Cove children's TSO was greater than in Tiong Bahru. We explain such findings in terms of children's facilities available in the two areas and access to those facilities. At Tiong Bahru there is only one play ground. Children from the nearest buildings are the ones who use the playground frequently. Children from distant blocks cannot access the playground without crossing a vehicular road. At Punggol this is quite the opposite. Parents' opinions on the constraints for COP concur with such explanation.

Parents in Tiong Bahru reported 'few children's facilities' more than parents in Punggol as a cause for reduced COP.

Table 4: Reported children's average time spent outdoors (TSO)

Average TSO in terms of age, gender and place (in hrs/day)		
Age (years)	7-11	1.27
	12-14	.64
Gender	Male	1.23
	Female	.8
Study areas	Tiong Bahru	.9
	Punggol Cove	1.2
Total		1.1

Screen time (SCT) versus Outdoor Playtime (COPT)

The phenomenon of increased children's screen time compared to children's outdoor playtime is associated with obesity and other negative health impacts such as 'nature-deficit disorder' (Louv, 2010). In both the study areas, screen time was more than outdoor playtime reported by the children during both school days and school holidays. During school days, for all children, the average COPT was 76 minutes per day whereas average SCT was 93 minutes per day. Girls were more attracted to TV and computer games than boys were. During schooldays, girls spent more than 100 minutes per day playing with screens whereas boys reported 32 minutes per day for the same activity. Boys' COPT was also higher than girls' COPT on both school days and school holidays.

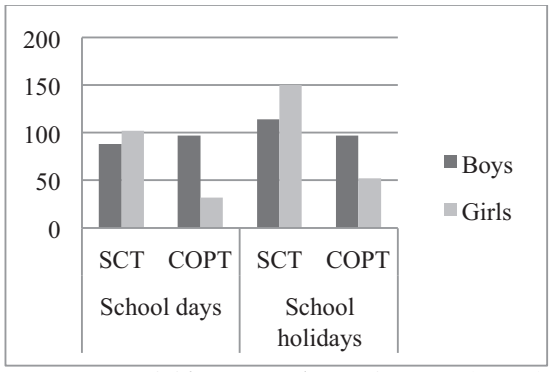


Figure 3: Children's outdoor playtime (COPT) versus screen time (SCT) in School days and school holidays (in minutes per day)

Our study supports earlier findings in the context of Singapore. Earlier studies found that children's screen time (SCT) is increasing in the urban areas compared to children's outdoor playtime (COPT). In the context of Australia, children's, aged 12, screen time (more than 2 hrs/day) was found to be more than children's outdoor playtime (less than 0.5 hrs/day) (Wen et al., 2009).

Causes for Reduced Outdoor Play

The main reasons for decreased outdoor play presented in the HDB 2008 report were children's involvement in computer games and enrichment classes in schools. Parent's opinions resemble such findings along with identifying the physical aspects such as roads and the non-availability of play facilities. During interviews with parents, we asked their opinion regarding reduced outdoor play of children within the neighborhood. The majority of parents reported 'educational pressures and other competitions' (50%) as the major cause for reduced COP followed by 'lots of cars outside in the streets' (31%); the 'outdoor is not safe and secured' (25%); 'lots of unknown people outside'(19%). The issue of parental concern for their child's educational achievement in the context of Singapore deserves further attention in the discourse of child friendly cities (CFCs). Future research may consider devising innovative research methods on how to enhance outdoor play activities through educational programs, rather than 'education' as a hindrance to children's sufficient outdoor play. The integration of schools and home in landuse planning and designing safe ways to school can play role in this regard.

CONCLUSION

Outdoor play develops resilience. 'Children playing outdoors independently' is a strong indicator of the social cohesiveness of a community. In the greater debate of increasing urban resilience, efforts for creating friendly environments for children's outdoor play demands greater attention. In the context of Singapore, this paper has initiated such efforts by delving into the nature of children's outdoor play behavior in the existing planned housing environments. Minimal reported unstructured play and natural contact, reduced time spent outdoors and associated 'educational pressure' can contribute in instigating policy debate. Two built environmental aspects, among others, came to the foreground of planning and housing (re) design discussion: road patterns with a specific focus on children's access to outdoor places, and the co-presence of facilities where a diverse group of people can interact and see each other. We suggest further research on the ways to enhance child friendliness of urban areas by taking integrated planning and (re)design approaches involving all relevant stakeholders.

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ENERGY COLLECTING PERFORMANCE OF BUILDING INTEGRATED WATER STORAGE FAÇADE SYSTEM FOR HOT CLIMATE APPLICATION

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ABSTRACT

Due to its equatorial location, Singapore receives high and constant solar radiation throughout the year. And the warm weather is accompanied by minimal daily and annually temperature variation because of its maritime exposure. The natural climate provides an advantage to utilise solar energy for sustainable development. This paper proposes a water storage façade system that can collect solar energy for daily usage and reduce space cooling loads for buildings. It utilizes water for absorbing and storage thermal energy and can be integrated into external walls of building easily for energy saving. The theoretical analysis of the proposed water storage façade was set up based on a 1-dimensional heat transfer model. Its water-heating performances were investigated by numerical calculation and experiment verification. The analysis results of water temperature were found influenced by time step and wind speed.

INTRODUCTION

Located in hot climate regions, Singapore receives a fair amount of solar radiation throughout the day. The total incident solar radiation can reach as high as 1,000 W/m^2 during the diurnal peak period from 11 am to 1 pm and an average of 500 W/m^2 in a day, usually. The 'heat gain' by a typical modern high-rise building from solar radiation is transmitted mainly through the external walls or façades. A small amount of the solar radiation is reflected by the façade walls to the surrounding while a substantial portion is absorbed as thermal energy. This thermal energy can cause the surface temperature of the façade walls to rise to around 20^{o}C above the ambient temperature. With this abundant amount of free renewable energy source, it is favourable for solar technologies to be developed and implemented in Singapore. The constant solar radiation level as shown in Figure 1 is a bonus to guarantee a constant supply of solar energy is available in Singapore.

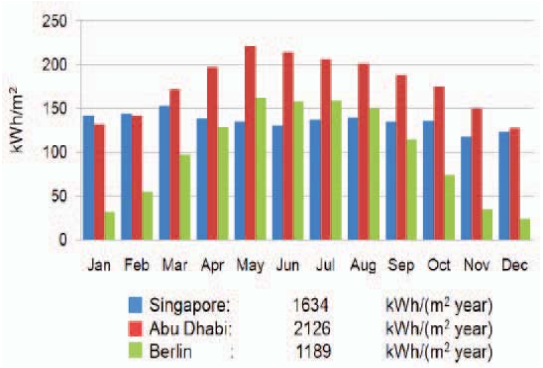


Figure 1 Monthly solar radiation at selected sites (Luther, 2010)

Although the Building Integrated Photovoltaic (BIPV) façade system has been used to collect the solar energy, it is still a very complex and costly option. Water is a cost-effective and ideal storage and insulation medium for harnessing the solar energy due to its high specific heat capacity. Therefore, some literatures about the integration of photovoltaic and thermal (PVT) system into building to maximize the energy harvesting capability on a building façade are available. Theoretical and experimental analysis is performed based on a façade-integrated photovoltaic/water-heating system by Chow, He, & Ji in Hong Kong (Chow et al., 2007). The proposed water storage façade panel is designed to be similar to a flat plate solar collector. Matuska and Sourek have performed several parametric analyses on PVT collector/façade area ratio, collector configurations, slope angle, air gap and the effect of air velocity for a typical building (Matuska et al., 2006). A useful finding from the analyses is that the heat gain of building is negligible if thermal insulation is sufficiently high. Tripanagonostopoulos conducted extensive studies on various configurations to maximize the performance of a PVT design (Tripanagonostopoulos, 2007). In this paper the proposed water storage façade system is an economical and efficient solution for buildings to store the solar energy for daily usages. In the meantime, it also can reduce heat penetration due to solar radiation.

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SIMULATION

There are three major mechanisms in heat transfer, namely conduction, convection and radiation, which thermal energy can be transferred across mediums.

Computational Model

The theoretical analysis of the water storage façade can be set up based on a 1-dimensional model due to the form of the water storage façade that was shaped as a panel. The single dimension was spanned across the *x*-direction with the front absorber plane (denoted as subscript *a*) facing outwards towards the radiation and the back facing plane (denoted as subscript *b*) facing towards the façade of the building as shown in Figure 2. The plane was idealized to extend infinitely along the *y* and *z*-axis. Hence, the analysis result is expressed in per unit area on the y-z plane. In the analysis, 7 nodes shown in Figure 1 are set up across the x-direction on the points of interest.

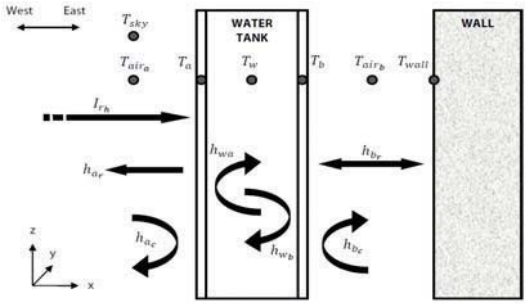


Figure 2 Schemetic diagram of the computational model

Energy Balance Equations

The core concept for the setup of the model is directly related to the principle of conservation of energy. Based on this concept, the changes in energy in a system is the net of energy that enters and leave the system. By defining a unit of water storage façade as a closed system, the three governing equations derived based on energy balance is expressed in equations below.

$$M_a C_a \frac{\delta T_a}{\delta t} = I_{rh}\alpha_a - h_{ar}\left(T_a - T_{sky}\right) - h_{ac}\left(T_a - T_{air_a}\right) - h_{wa}\left(T_a - T_w\right) \quad (1)$$

$$M_w C_w \frac{\delta T_w}{\delta t} = h_{wa}\left(T_a - T_w\right) - h_{wb}\left(T_w - T_b\right) \quad (2)$$

$$M_b C_b \frac{\delta T_b}{\delta t} = h_{wb}\left(T_w - T_b\right) - h_{ba}\left(T_b - T_{air_b}\right) - h_{br}\left(T_b - T_{wall}\right) \quad (3)$$

and $M_a = \rho_a A_a X_a$,

$M_w = \rho_w A_w X_w$,

$M_b = \rho_b A_b X_b$.

Where δ is the change of parameters. α is absorptivity. M is mass. C is specific heat capacity. h is heat transfer coefficient. I_{rh} is horizontal solar radiation intensity. A is surface area. ρ is density. X is material thickness.

All inputs in the mathematical model are dependent on the climate data at a predefined location. As the daily weather data changes with time, it is not practical and logical to solve the series of equations in first order partial differential equation that yields a steady state solution. Therefore, a computation method based on explicit finite difference method which requires the linearization of higher order differential equation is commonly adopted for transient heat transfer analysis. This can be done by the discretization of continuous time dimension of the model into time steps that is sufficiently small. This reproduces the equations into a finite-difference algorithm as expressed in equation below.

$$T_{a,t_{n+1}} = T_{a,t_n} + B \cdot \frac{t_{n+1} - t_n}{\rho_a C_a X_a} \quad (4)$$

where

$$B = \left[I_{rh}\alpha_a - h_{ar}\left(T_a - T_{sky}\right) - h_{ac}\left(T_a - T_{air_a}\right) - h_{wa}\left(T_a - T_w\right) \right]_{t_n}$$

$$T_{w,t_{n+1}} = T_{w,t_n} + \left[h_{wa}\left(T_a - T_w\right) - h_{wb}\left(T_w - T_b\right) \right]_{t_n} \cdot \frac{t_{n+1} - t_n}{\rho_w C_w X_w} \quad (5)$$

$$T_{b,t_{n+1}} = T_{b,t_n} + D \cdot \frac{t_{n+1} - t_n}{\rho_b C_b X_b} \quad (6)$$

where

$$D = \left[h_{wb}\left(T_w - T_b\right) - h_b\left(T_b - T_{air_b}\right) - h_{br}\left(T_b - T_{wall}\right) \right]_{t_n}$$

In order to simulate the model to a higher degree of accuracy, properties of water is calculated and updated in each time step based on its correlation with temperature shown by Sokolov and Vaxman (Sokolov et al., 1983).

Assumptions

The assumptions in the analysis are listed as in the following:

Considering that the thickness of the water façade panel is significantly smaller than the width and height of the panel, current computational model assumes no boundary at in the y- and z- dimension.

The temperature is assumed to be constant within same medium. As a result, any temperature gradient that may exist within the same material is not accounted. The assumption is valid provided that the thickness of each material (e.g. the front and back plate) is considerably small, and accordingly the temperature difference within the medium is also small.

There is no emissivity heat exchange between the absorber plate and the back plate. It is expected for the two plates to be made of the same material and hence the emissivity is expected to be the same. As the temperature difference between these two plates is minimal, the energy gain/loss is negligible.

The air layer between the back plate and the exterior wall of the building is assumed to be stagnant due to very small thickness of the air. Hence there is no forced air convection component in the calculation of the convective heat transfer coefficient for the back panel.

EXPERIMENT

The performance of water storage façade system has been further studied through conducting an experiment at Yongnam X-Station. The measurement data served as an empirical comparison against the simulated results. A test rig for the water storage façade system was constructed by Yongnam Ltd. Three water storage façade panels painted in white, orange, and black were mounted vertically and facing west to simulate the performance of the panel. Schematic of the experiment setup is shown in Figure 3. The water storage façade panels were fabricated in S275 hot rolled structural steel with the thickness of 5mm. The depth of water tank was 50mm.



Figure 3 Experimental Rig in YongNam X-Station

Data Collection

The HOBO Weather Station [H21-001] about 1 meter away from the water storage façade panels was set up to record climate data at the site of experiment. Weather data recorded by the weather station includes the ambient air temperature, dew point temperature, and relative humidity. In addition, 3 Silicon Pyranometer Smart Sensors [S-LIB-M003] were installed to record the intensity of solar radiation from the sky, horizontally from the west direction, and reflected radiation from the ground. The weather station logged the climate data in the frequency of 5 minutes throughout the period of the experiment. Temperatures at the points of interest were measured using some wire thermocouples connected to Omron Portable Multi-logger [ZR-RX40]. The other properties steels were obtained through various sources, and are summarized in Table 1.

Table 1

Material Properties for Steel

PROPERTY	VALUE	UNIT
Absorptivity, α	0.97	-
Emissivity, ε	0.95	-
Density, ρ	7870	kg/m^3
Specific heat capacity, C	470	J/kg·K

DISCUSSION

The water temperature in the façade panel was used as the basis of comparison between the simulated and experimental results. Key parameters such as the horizontal solar radiation and the ambient air temperature were included in the plots.

From Figure 4 to Figure 7, we can see that the overall trend pattern of the analytical model is consistent with the experimental results. The heating reaction of water due to solar radiation in the model is seemed slower than the experimental result, and the peak water temperature of the model is a bit lower than the experimental results. Based on the results in Figure 4 and Figure 5, the water in the façade tank is able to approach 50°C in the clear sky days measured. The computed temperature for water during overcast and rainy days also shows good conformity with the actual measured temperature shown in Figure 6 and Figure 7.

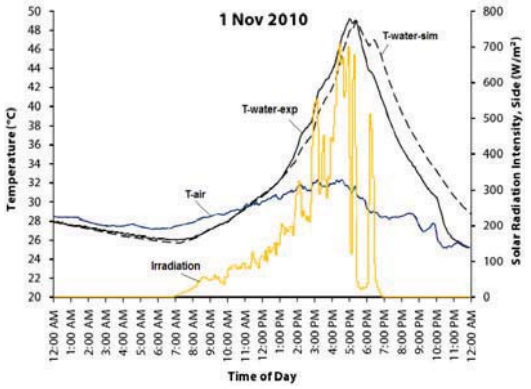


Figure 4 Comparison of Analytical and Experimental Results on 1/11/2010(clear days)

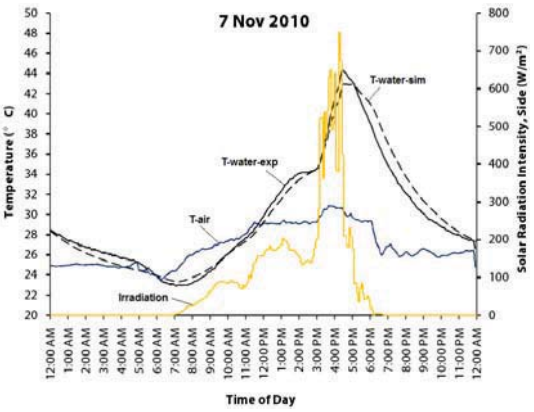


Figure 5 Comparison of Analytical and Experimental Results on 7/11/2010(clear days)

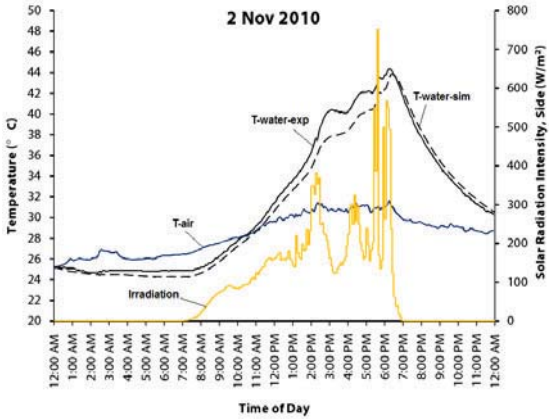


Figure 6 Comparison of Analytical and Experimental Results on 2/11/2010(overcast and rainy days)

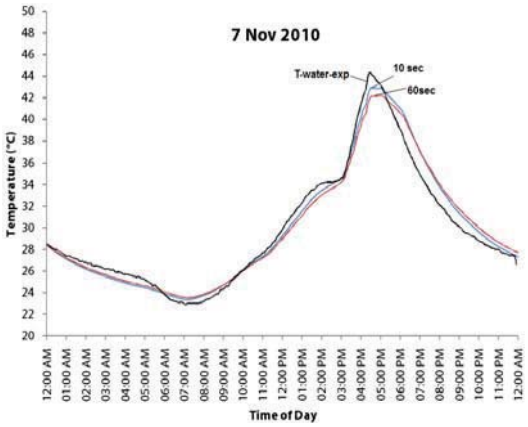


Figure 8 Influences of time step (left) and wind speed (right) on analysis results

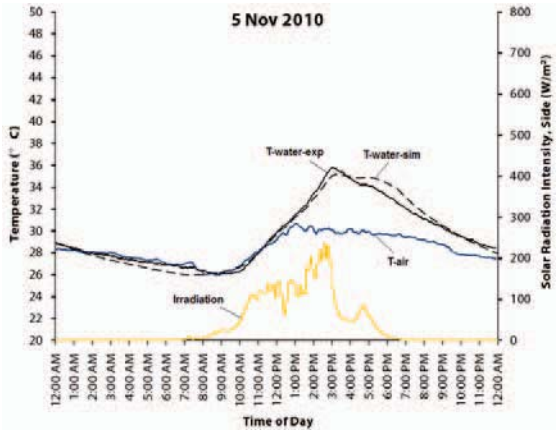


Figure 7 Comparison of Analytical and Experimental Results on 5/11/2010 (overcast and rainy days)

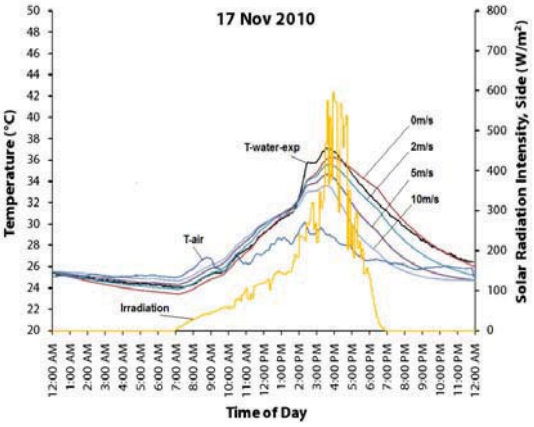


Figure 9 Influences of time step (left) and wind speed (right) on analysis results

Time step has an influence on the degree of accuracy that a numerical analysis can achieve. A simulation was run to compare the sensitivity of the analytical model due to time step. The input data on 7th November 2010 were computed with the time step of 60 seconds and 10 seconds and the results are shown in Figure 8 and Figure 9. Through observation, the plots based on 10 seconds time step are closer to the experimental result, hence depicting a higher accuracy. Thus, a smaller time step was proven to be beneficial to increase the accuracy of the numerical analysis.

The wind speed was assumed to be 1 m/s constantly throughout the analysis. However wind speed in the actual climate condition was highly variable. As the wind speed affects the convective heat transfer coefficient of the absorber plate, it is necessary to examine the influence of wind speed on the temperature of the water. The analysis was done based on data on 17th November with wind speed 0 m/s, 2 m/s, 5 m/s, and 10m/s, as shown in Figure 6. The simulation results showed that the water temperature is sensitive against the wind speed. A higher wind speed caused the temperature of the water to deviate closer towards to the ambient air temperature. As a result, a certain degree of error resulted from the assumption of constant wind speed due to the limitation of the available measured data was observed.

CONCLUSION

The proposed water storage façade system is a promising technology that can assists in decreasing the energy required for heating appliances such as domestic water heater by harvesting the solar energy stored in the water façade and reducing the space cooling load by minimising solar heat penetration. Its successful application may be an environmental, economy and social friendly solution to contribute to achieve the energy efficiency benchmark for both existing and new buildings. The water-heating performances of the system have been studied through both theoretical and experimental analysis. The influences on analysis results of some parameters such as selected time step and wind speed also were investigated in this paper. The system is expected to be available in various fitting options to allow its

applicability across different conditions and requirements.

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NOMENCLATURE

δ	change of parameters
α	absorptivity
M	mass
C	specific heat capacity
h	heat transfer coefficient
I_{rh}	horizontal solar radiation intensity
A	surface area
ρ	density
X	material thickness
t	time
T_a	temperature of front panel of water tank
T_b	temperature of back panel of water tank
T_w	water temperature
T_{sky}	sky temperature
T_{wall}	temperature of building wall

METHODOLOGY FOR THE ASSESSMENT OF ENVIRONMENTAL CERTIFICATION IN CONSTRUCTION: A CASE STUDY

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ABSTRACT

The construction industry is one of the sectors that affect the environmental equilibrium most. To mitigate this problem, guidelines and environmental certification processes for projects are proposed through the granting of Environmental Seals, to evaluate and verify the reduction of environmental impacts. When implementing a certification in a particular region, it is essential to study and adopt the methodology of analysis to ensure the certification process is effective and realistic to the country's situation. Therefore, this paper describes a case study of a certified construction project at a construction site, which is considerably sustainable, and identifying the solutions adopted to minimize environmental impacts. The project was LEED certified in the Gold category. The results indicate that it is necessary to be familiar with the assessment methodology, with the support and guidance of experts during the certification process, and understand possible variations from the regional localization.
Keywords: *Good Practices, Construction Site, Sustainability, Environmental Certification, Green Seal.*

INTRODUCTION

Notably, civil construction is an extensive process involves development of human settlements and infrastructure to support the development of a region or sector (CSIR Building and Construction Technology, 2002). This includes extraction and processing of raw materials, manufacture of construction materials and components, design cycle and execution of the project, and management and operation of the built environment.

Since 1990s, discussion on sustainability begins to involve a systemic understanding of the social, economic and environmental issues in each sector or industry. In the social field, the construction industry is one of the sectors that provide the greatest employment in the world, generating numerous indirect jobs. In the economic sphere, a considerable portion of the GDP of each country is influenced by the development of construction industry. In the environmental sphere, the construction industry consumes considerable amounts of energy during the extraction and industrialization of materials, resulting high wastage of materials and generating construction debris, consequently raises the need to reduce maintenance costs of projects. Thus, several actions in civil construction have been adopted to reduce the impacts caused by the industry, focusing on the entire production chain, led to "sustainable construction".

According to the Green Building Council – GBC (2013), Brazil is ranked the fourth place in the world in terms of sustainable or green buildings, with 51 certified buildings and 525 in the process of obtaining certification process, after the United States, the United Arab Emirates and China. The GBC contends that sustainable development of construction industry involves the adoption of best practices and an integrated process of design, construction and operation of buildings and constructed spaces.

Thus, the certification process also includes construction execution process. According to Araújo (2009), a building's construction phase accounts for a significant portion of its overall negative environmental impacts, especially loss of materials and generation of construction waste. These impacts affect the surroundings of construction site in the aspects of physical, biotic and anthropic environment where the building is located.

There are different types of environmental certification method for construction projects, such as the BREEAM (Building Research Establishment Environmental Assessment Methodology): a pioneering assessment method created in the U.K. in 1990, the LEED (Leadership in Energy and Environmental Design): created in the U.S. in 1994, and the HQE (Haute Qualité Environnementale): released in France in 1996. In general, these systems seek to reduce the carbon footprint of the built environment and create a competitive system to increase the efficiency of buildings.

According to Silva, Silva and Agopyan (2003), the LEED certification has simpler structure and assesses the building as a whole, involving the entire production chain of the construction. The first phase

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of analysis in the certification process is the "Project Design Review," which involves the entrepreneur providing all the information regarding the phases of the project in order to receive feedback that may come warn him about steps to be taken to achieve environmental certification.

According to the GBC (2013), the Construction Environmental Management Plan should be prepared during the execution phase to minimize environmental pollution and prevent and control environmental impacts of the construction site, such as demolition debris, control of suspended solids, removal of vegetation, soil contamination, water and electricity shortages, etc.

Thus, in order to show the scope of certification of a project, this article will present a case study of a project that uses sustainable concepts during its execution phase, recognized by LEED certification. On-site visits to the construction site were made to identify good practices, using the checklist proposed by Araújo (2009) to verify compliance with sustainability requirements in the execution of the construction works.

SUSTAINABILITY IN CONSTRUCTION

The term sustainability can be defined as "something that is sustainable." This can be analyzed so that any society or development process can satisfy its needs without compromising future generations. Creating a sustainable world therefore means creating a less aggressive world (MATEUS, 2005). According to Silva (2007), the term sustainability is defined as "development that ensures the needs of present generations without compromising the ability of future generations to develop".

Following this line of reasoning, Araújo (2009) states that sustainable construction aims to produce a constructive system that promotes conscious changes in the surroundings, in order to meet the needs of the building, housing and use by modern man, preserving the environment and natural resources, ensuring quality of life for current and future generations.

According to the Council for Scientific and Industrial Research (CSIR, 2002), sustainable construction in developing countries tends to focus on the relationship between building and human development, often marginalizing environmental aspects. However, given the serious environmental degradation experienced by most of the developing world, the construction industry cannot continue to ignore the environment.
Marinelli (2009) notes that some entrepreneurs use sustainability to attract potential buyers to the product based on the economic factor. Thus, many real estate builders include sustainable novelties in their buildings, using the term "sustainable construction" as a marketing ploy to boost their sales and profits.

THE LEED CERTIFICATION

Silva (2007) considers that the aspects evaluated by LEED refer to the environmental impacts resulting from the processes related to the building (design, construction and operation), which involve aspects relating to the building site, such as water and energy consumption, the use of local materials, management of wastes, and the comfort and quality of the building's internal environment. The assessment method consists of analyzing the building's potential environmental efficiency based on documents that indicate its compliance with the required and classificatory items for certification.

The LEED method is used to compare the environmental performance of a building against that of another based on the sum of credits of 1-110 (10 points are bonus) in the LEED version 3 (V3) released in 2009. The four levels of certification and corresponding scores are Certified (40-49 credits), Silver (50-59 credits), Gold (60-79 credits) and Platinum (80+ credits), according to the GBC (2013).

In Brazil, LEED certification has been applied mainly to corporate buildings in compliance with specific rules that define criteria to be met by the project, considering six major chapters:

1. Sustainable choice of land.
2. Rational use of water.
3. Rational use of energy and air emissions.
4. Material consumption and waste management.
5. Quality of the built environment.
6. Innovation process and project design.

According to the GBC (2013), the LEED for Core & Shell v2.0 precertification granted by the U.S. Green Building Council – USGBC has been used by builders and developers who are developing a project for later commercialization of its rooms, ensuring the future user that his facilities provide all the conditions for high performance of the project. This certification covers all the common area, the air conditioning system, the main structure such as stairwells and elevators and facades, facilitating the certification of commercial interior rooms. The details of occupation, such as furniture, are not considered in view of the variety and independence of their future occupants.

For Araújo (2009) and others authors, the main assessment methods are based on shared guidelines such as:

- sustainable planning of the construction,
- passive use of natural resources,
- energy efficiency,

- water conservation and management,
- management of the building's wastes,
- air and indoor environment quality,
- acoustic comfort,
- rational use of materials, and
- the use of environmentally friendly products and technologies.

Although these methods differ in how the assessment is performed, in their scoring criteria and in their considerations. There is no classification to characterise how projects differ locally and regionally or the way of execution.

RESEARCH METHODOLOGY

As mentioned earlier, the methodology developed by Araújo (2009) was used here, based on LEED certification, which involves analyzing the correlation between the adopted measures and the resulting impacts. This author pointed out that where a correlation is found between an aspect and an impact, a value can be assigned by "prioritization," which is understood as the adjustment of relationships and degrees of importance given according to the conditions of each construction site. To consider this requires first establishing clear priorities.

However, this priority was not standardized, and might be determined by the geopolitical conditions of a given region. In the case of Brazil, regions with low rainfall, for example, may give priority to the item 'collection of rainwater,' compared to tropical regions. In other words, it is implicit that in Brazil's northeast region, concerns about the use of rainwater and the reuse of water from the construction site must be greater than in the northern region, in order to take advantage of sustainable techniques to offset the deficit generated by water shortages in some areas of the region.

Based on the matrix proposed by Araújo (2009), the main environmental aspects were observed are generation of inconveniences and pollution, generation of construction and demolition debris, water and energy consumption and waste at the construction site, and the implementation of transformation activities of the production.

The environmental impacts were proposed based on Degani (2003), whom proposes the division of interferences by the affected environments: physical, biotic and anthropic, the first subdivided into soil, water and air. The anthropic environment is subdivided according to the extent to which it is affected: workers, neighborhood and society. The biotic environment considers interferences in the local flora, fauna, and changes in the dynamics of local and global ecosystems.

Thus, Araújo (2009) proposed the inclusion of other data on the practices of the construction site in the analysis of the project's sustainability, listing the following topics of analysis:

- **Resources**:
  - Reduction of water consumption and waste
  - Reduction of energy consumption and waste
  - Use of solar energy
  - Collection of rainwater
  - Correct use of resources
- **Processing and consequences**
  - Adoption of appropriate tools and techniques
  - Separation of generated wastes
  - Use of personal protective equipment
  - Less on-site processing
- **Wastes**
  - Waste recycling actions
  - Control of material losses
  - Proper disposal of renewable wastes
- **Construction site infrastructure**
  - Water reuse at the construction site
  - Use of rainwater at the construction site
  - Depletion of wastewater
  - Non-occupation of the public thoroughfare
  - Use of lands outside the construction site
  - Provide worker training

Based on these assessment items, in this case study, documents of the construction project were examined, interviews were held with stakeholders participating in the execution of the work, and a photographic record was made of good sustainability practices. The information obtained in this case study allowed us to compare items, redefine strategies and adapt actions to meet the requirements of the LEED certification process.

CASE STUDY

The project was selected because it presents sustainable concepts in both its construction and post-occupancy phases in which obtaining LEED for Core & Shell Development precertification. Precertification is a formal recognition given to a candidate project that established a goal of obtaining LEED certification. This would enable the owner of the enterprise to market it to potential tenants and financiers, whom highlight its green features.

In this project, precertification also served to guide changes in architectural design to incorporate sustainability recommendations such as a promenade with a larger green area, a change in the material used on the facade of the lower part of the building, and the adoption of openings where the side walls meet to facilitate ventilation. The study was conducted at the construction site after these changes were implemented.

The construction site is located in the state of São Paulo, Brazil. The project, which is directed at commercial clients, consists of a business tower situated adjacent to a future shopping mall. The land on which the tower is built comprises a total area of 31,782 m² and 51,088 m² to the mall. The overall construction of the project was divided into two phases. The first phase was monitored in this case study, consisted of the construction of the tower with a total of 36 floors, 3 basement garages, 1 mezzanine floor, 1 ground floor, 1 convention floor, 1 technical floor, 26 commercial floors, an engine room, an attic, and a roof with helipad. The second phase consisted of the construction of the new shopping mall, which was executed by another contractor.

The building was executed with a conventional reinforced concrete structure cast on site, closing with concrete masonry and stone panel finishing in the common areas. One of its sustainable solutions is the delivery of floor slabs covered only with subflooring, allowing the real estate property to be customized. The design included the installation of raised floor on the commercial floors as a way to reduce material losses and the generation of wastes in post-occupancy phase when modifications for the passage of extra piping might be required.

GOOD PRACTICES AT THE CONSTRUCTION SITE

Various good sustainability practices were observed at the construction site, as described below. Throughout the execution phase of the project, the water consumed at the construction site was reused, in addition to rainwater. The water was stored and treated for activities that require lower water quality, e.g., washing streets, flushing toilets, washing machinery, etc. Figure 1 illustrates the piping system for treating reused water, while Figure 2 shows the water treatment plant. This figure also shows a worker using personal protective equipment (PPE), which is a social aspect of sustainability.

To reduce electricity consumption and waste, the building's installations were sized correctly and executed by qualified professionals, using specified good quality materials. The electrical installations are fixed to the building temporarily, as illustrated in Figure 3, to facilitate their removal and reuse.

To reduce the disposal of recyclable wastes in landfills and dumps, waste separation bays (Figure 4) containing waste bins (Figure 5) were built at the construction site. The recyclable wastes were stored separately according to the type of material, and removed periodically from the construction site by a waste picker cooperative that delivered them to its recycling centre.



Figure 1 – Pipes for recycled water used at the construction site



Figure 2 – Small water treatment plant at the construction site



Figure 3 – View of designed electrical installations



Figure 4 – Recyclable waste storage bays



Figure 5 – Waste bins for collecting recyclable wastes



Figure 6 – Use of an adjacent land for stocking and processing material

To optimize the workspace at the construction site, the company rented a neighboring land for stocking material and constructing reinforced concrete elements, as shown in Figure 6. This rendered the work environment safer, without the overlapping of physical flows of materials and people moving around at the construction site.

The land was drained by pumping water away from the construction site using devices called decantation boxes (Figure 7), where the water was sent to the public drainage system. In these boxes, the solid and the mixture with greater (sediment and wastes) weight were decanted, after which the decanted passed through a geotextile filter before flowing into the public drainage system.

Before leaving the construction site, all trucks passed through a wheel wash to prevent dirt and mud from reaching the street. The wheel wash consisted of a stretch of paved ground containing a shallow water tank through where the trucks passed pass, as illustrated in Figure 8. The water in the wheel wash was also connected to the aforementioned decantation boxes.

Before leaving the construction site, all trucks passed another more specific device, a concrete washout tub used at the construction site that served the same purpose as the wheel wash, but consisted of a concreted and waterproofed hole in the ground, as shown in Figure 9. The wastes and leftover concrete produced by the concrete mixer at the construction site were deposited in this tub through the washing process. It was observed that the material accumulated in the concrete washout tub was later used as on-site landfill material, as shown in Figure 10.

One of the soil preservation measures at the construction site were fuel catchment trays filled with material for absorbing petroleum products. These trays were placed at points of potential leakages of oil, grease and the like, e.g., under truck engines and machines, as illustrated in Figure 11.

Another important practice was the construction of a classroom for worker training courses at the construction site (Figure 12) for the transmission of technical and management information. Planning and effectively using this space was an important point in the process of sustainability certification.



Figure 7 – Decantation box for water used at the jobsite



Figure 8 – Wheel wash



Figure 9 – Concrete washout tub



Figure 10 – Use of construction debris on-site



Figure 11 – Fuel catchment tray



Figure 12 – Classroom for worker training courses

ANALYSIS OF THE CERTIFICATION METHOD

The company hired a LEED accredited professional to monitor and provide guidance on the certification process, offering detailed information to all stakeholders, keeping records of meetings, reports and projects, and ensuring the correct interpretation of scoring criteria and the implementation of good sustainability practices.

This is due to every enterprise that requires LEED certification would receive periodic and biweekly visits for verification of compliance, necessary actions and changes that would be required to comply with the analyzed items, according to the type of certification that is sought. The accredited professional wrote a report after each visit, containing all the guidelines, required changes, the person responsible for each changes, the deadline for each changes, and compliances achieved by the project. The report generated a score, which facilitated the overall monitoring of the certification process, including the evolution of the project's score, as illustrated in Figure 13.



Figure 13 – Monitoring the LEED scorecard in Brazil

The following main corrections were identified are effective use of personal protective equipment; non-release of solid wastes into storm sewers; frequent cleaning of the construction site; improved storage of materials; and separation of wastes.

Following the certification guidelines, the company also implemented different initiatives at the construction site, such as those cited in this article. Thus, some of the measures evaluated by LEED, whose compliance was or was not detected during this case study in Brazil, were:

- Access to public transportation – Compliant (there was a bus stop 380 meters from the entrance to the building);
- Bike parking lot – Compliant (there were 143 spaces for bicycles, more than 30% of the population are expected to use the building, which corresponds to 2014 people);
- Vehicles with low emissions and low consumption – Compliant (50 exclusive parking slots closer to the main entrance);
- Area free of construction – initially not compliant (39% of the area was not built, while the certification required 40%);
- Rainwater drainage – Compliant (implementation of the drainage project reduced the infiltration rate by more than six-fold, and the rainwater collection and reuse project foresaw the use of a volume in excess of 186 m^3/day at the site);
- Coverage – Compliant (631.42 m^2 of green area, corresponding to 56% of the coverage area, excluding the areas for machinery);
- Innovative sewage technologies – Compliant (the use of gray and black water tanks to supply the toilet flushing system eliminated the use of drinking water for this purpose);
- Reduction in water consumption – Compliant (a savings of 30% was achieved through the adoption of recycled water for toilets and urinals, allied to the use of water efficient taps);
- Storage area for recyclables – Compliant (once it is in operation, the building will have a total area of 80.30 m^2 in the common area reserved exclusively for the storage of recyclable wastes, according to the specific guidelines of LEED in terms of accessibility, odor, separation, size and waste logistics).

To ensure the desired operating performance, the building contractor developed prototypes and performed simulations during the execution of the construction, in order to test the constructive solutions to be implemented in the project. Thus, the project was analyzed according to the LEED methodology and the strategies adopted, has achieved Gold certification.

According to the assessment proposed by Araújo (2009), the project complied with all the items listed as priorities in the correlation measures with respect to environmental impact. However, the results obtained in the analysis indicated that social, economic and cultural factors were considered less relevant in the certification under study.

CONCLUSION

Albeit difficulties, it is very important to comprehensively define the sustainability of a construction project. Sustainability is not just about managing wastes or performing selective waste collection at the construction site. A company or project is to be considered sustainable, that aims to "achieve" sustainability, should not perform only single specific actions, such as managing its wastes but neglecting the reduction of energy consumption, or encouraging selective waste collection, but should

employ various strategies systemically. It should also consider the surroundings of the building and the set of actions that can be adopted to minimize environmental impacts. Many of the practices identified in this study could be widely disseminated and implemented for construction sites to be considered more sustainable.

For a more in-depth discussion of the subject and to trigger new discussions and ways of thinking, one could argue that certifications may be granted or issued erroneously because, without a pre-established benchmark, it is virtually impossible to make an effective and correct comparison of certified projects. The verification of the influence of each environmental aspect in the generation of an impact is highly subjective; hence, decision and assessment parameters are needed according to identified local priorities.

Thus, it is considerable important to obtain certification seals to facilitate the processes of economic, social and environmental sustainability, providing information for society and continuing to include the country in the list of practitioners of sustainable construction.

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RESOURCE RECYCLING OF WASTE GLASS AS GREEN BUILDING MATERIALS

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ABSTRACT

In this work, we report an energy saving and eco-friendly method for the production of foam glass which can be used as a building material. Foam glass prototypes (40 × 40 × 10 cm) and foam glass bricks (7.5 × 7.5 × 25 cm) with high open porosity (85-95%), low density (0.15-0.25 g/cm^3), high compressive strength (1.0-2.0 MPa) were successfully produced. Foam glass samples show uniform pore size, low thermal conductivity (0.067 W/m^{o}K) and relative high sound absorption coefficient (0.5). This foam glass material has potential application as partition wall in building structures due to their low thermal conductivity and high sound absorption coefficient. In addition, their high porosity implies that they are light and will significantly reduce the load on the building. They are also fire-proof and could have anti-bacterial property. The foam glass is also non-toxic, which adds to the eco-friendly nature of the product.

INTRODUCTION

In Singapore, the amount of solid waste generated has increased over the decades from 0.74 million tons in 1972 to 6.89 million tons in 2011. The waste generation per capita was approximately 3.64 kg/day in 2011. The existing landfill, Pulau Semakau landfill which was built in 1999, is estimated to last till 2045.

In addition, with the increasing trend of waste generation, more incineration plants would be needed to be built every 7-10 years. This is not feasible for a land-scarce country like Singapore, and the costs of building and operating waste disposal facilities is very expensive. The capital construction costs of Semakau landfill is about $610 million and the fourth incineration plant, the Tuas South incineration plant, is about $890 million. [1] Hence, it is necessary for Singapore to develop alternative ways for managing its solid waste.

In 2011, 59% of the solid waste generated in Singapore was recycled. However, materials like glass have a low recycling rate of only 29%. This is due to the lack of glass recycling plants in Singapore. Hence, the waste glass is collected locally, then are sorted and exported overseas. [1] The glass recycling technologies available (i.e. the conventional glass bottle recycling, the float process & fiberglass manufacturing) are energy-consuming and pollution-causing. Also, the glass recycling process may not be profitable as the glass product may not be much cheaper than the virgin glass in addition to the high initial construction, recurring operation and maintenance costs. [3-5]

If the glass waste is contaminated, it may be rejected by glass recycling plant. [5, 6] These glass wastes would be incinerated and landfilled, which would result in energy consumption and occupying valuable landfill space as they are non-biodegradable. [4]

To improve the glass recycling capabilities, foam glass technology is studied. Foam glass is a glass product with bubble-like cellular structure and high porosity of 80-97%, making it an ideal material for thermal insulation and acoustic insulation purposes. [1, 4, 7, 8] It is created with the gas expansion in a glass melt at temperatures between 700 to 900 ^{o}C. Injected gases maybe used, but a commonly method is the use of gas-producing substances from thermal decomposition called foaming agents. The gases from the foaming agents bubble out to create the porous body of the foam glass. [3]

Foam glass first commercialized in 1930's, was limited to the use of virgin glass as feedstock. However, with technological development, manufacturers succeeded in producing foam glass products with post-consumer glass. Generally, the specifications of the foam glass in the market are mainly its size, thermal conductivity, sound insulation ability, water absorption ability and mechanical strength. [9] Currently, the reported maximum size of foam glass block produced is of 1.2 m long by 0.6 m wide by 0.16 m thick. [10] The ideal density and thermal conductivity is between 0.13-0.30 g/cm^3 [10] and 0.037-0.058 W/m^{o}K respectively [11].

An independent study by the UK government initiated group – WRAP (Waste and Resources Action Programme) has shown that the use of foam glass in the construction of domestic and commercial buildings would greatly reduce the energy consumption and hence the carbon dioxide footprint of newly built structures.

It has been reported that any pore sizes larger than 4 mm is not suitable for construction application. [12] This is because the pore size determines the mechanical strength; larger pores will reduce the strength of the foam glass due to the thinness of the cell walls between the pores. [13] In 2008, Shutov et al proposed to conduct a more detailed analysis in determining the optimum pore size. [14]

Formulation and heating process are the most important parameters, which can affect the properties

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of foam glass. In 2009, Alejandro et al reported that by adjusting the foaming temperature and the holding time, the porosity and the microstructure of the foam glass can be controlled. [15] In 2010, Pokorny et al reported that the foaming process was not only affected by the foaming agents but also by the heating process. [16] A higher heating rate will increase the expansion of the glass, which creates a product with low density. [16]
Hence, it is necessary to develop a simple and eco-friendly method for the production of foam glass using low-grade waste glass as raw material. In this work, the formulation and heating parameters will be also optimized. The potential application of the obtained foam glass as lightweight partition wall will be studied.

EXPERIMENT

MATERIALS

As shown in Figure 1, a simple and energy saving method has been developed to produce foam glass with low density. Briefly, appropriate amount of glass powder, foaming agents ($CaCO_3$ and/or carbon black) and other additive (Na_2HPO_4) were ball-milled at speed of 350 rpm for 30 min to get fine powder. Then 12.0 wt% of binder (sodium silicate solution, 24%) was added into the fine powder and mixed unformly. After that, the mixture was put into a steel mould and compressed at high pressure using a hydraulic compressor. Finally, the samples were de-moulded before being sintered, which saved the energy consumption and the cost of steel moulds.

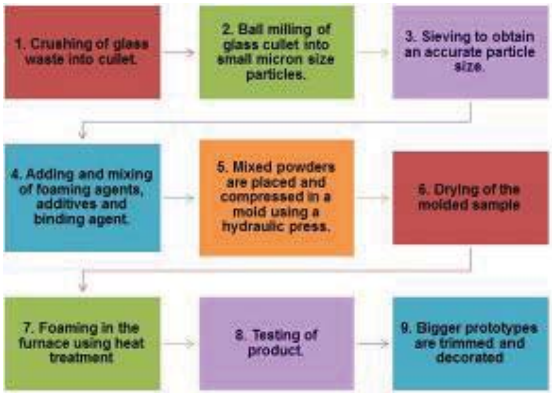


Figure 1. The flow diagram of the production process of foam glass prototype

HEATING PROCESS

A 3-segment heat treatment process shown in Figure 2 was designed to produce foam glass. In this work, the pre-heating temperature and foaming temperature were optimized. The sample was pre-heated to 450 °C at a heating rate of 15 °C/min and kept at this temperature for 30 min. Subsequently, it was heated to the foaming temperature of 900 °C at a heating rate of 10 °C/min and dwelled at 900 °C for 30 min. Afterwards, the sample was cooled down to annealing temperature of 600 °C naturally and dwelled at this temperature for another 30 min. Finally, the sample was cooled down to room temperature naturally.

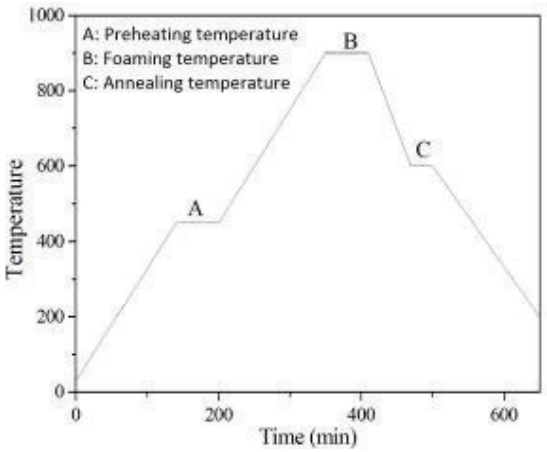


Figure 2. 3-segment heat treatment process

CUTTING & DECORATION

The foam glass prototypes were cut to rectangular shape using a milling machine and then decorated with different wall papers or hard papers.

CHARACTERIZATION

The properties of the product will determine its application. Hence the following output parameters will be tested:

1. Density
2. Porosity
3. Pores sizes
4. Compressive strength
5. Thermal conductivity
6. Sound adsorption coefficient

Density is determined by the formula:

$$Density = \frac{\text{mass of product}}{\text{volume}}$$

The mass of product was weighed using a mass balance (A&D company: Fz- 2000i model) and volume V_1 measured and calculated. A pycnometer was used to determine the porosity of the products (Quantachrome instrument: Ultrapyc 1200e model). Its uniformity of pores structure and the pore sizes was determined using a stereoscopic zoom microscope (Nikkon: SMZ 745 T model). The compressive strength of the foam glass was tested using a compressive strength testing equipment (FT-50). The thermal conductivity was done by an external company, Setsco Service Pte. Ltd, according to the ASTM C518 : 10 testing standard. The sound

adsorption coefficient of the foam glass prototype was tested by East Notice Certification Service Co., Ltd, according to testing standard of ISO 354 : 2003 Acoustics.

RESULTS AND DISCUSSION

Firstly, the heating parameters including pre-heating temperature and foaming temperature were optimized. All other parameters (foaming temperature: 900 °C, foaming agent: 3% $CaCO_3$, binder: 12%) were fixed and the pre-heating temperature was changed in the range of 400 – 600 °C. Because density is the most important parameter to evaluate the quality of foam glass, the densities of foam glass samples are discussed. The results of the foam glass prepared at different pre-heating temperatures are shown in Figure 3. It can be seen that the foam glass exhibits the lowest density of 0.37 g/cm^3 at 450 °C.

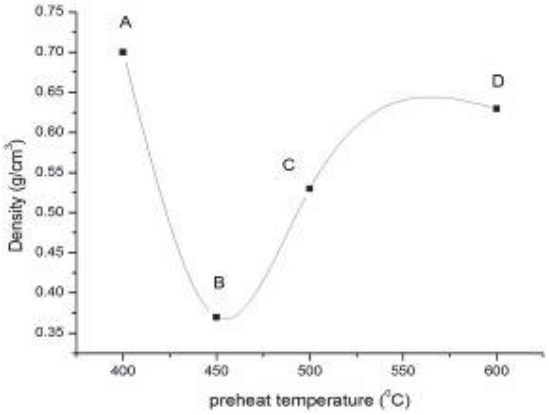


Figure 3. Densities of the foam glass samplese produced at different pre-heating temperatures

Then the pre-heating temperature was fixed at 450 °C and other parameters are remaining the same, except the foaming temperature. The foaming temperature was changed in the range of 850-925 °C. The densities of the foam glasses produced at different sintering temperatures are shown in Figure 4. It is obvious that the foam glass exhibits the lowest density of 0.37 g/cm^3 at the sintering temperature of 900 °C.

After optimizing the heating process (preheating temperature: 450 °C and foaming temperature: 900 °C) is used in the following experiments. The mixture of glass powder with 3% $CaCO_3$, 12% sodium silicate solution, and different amounts of carbon (0-5%) are used as raw material. The densities of the obtained foam glasses are shown in Figure 5. The results show that the addition of carbon can decrease the density of the foam glass and the lowest density is around 0.31 g/cm^3 when the content of carbon is 2%.

After optimizing the amount of carbon as foaming agent, the effect of different contents of Na_2HPO_4 has been studied. The mixture of glass powder with 3% $CaCO_3$, 12% sodium silicate solution, 2% carbon and different amount of Na_2HPO_4 (0-5%) are used as raw material. The densities of the obtained foam glasses are shown in Figure 6. The results show that the addition of Na_2HPO_4 can greatly decrease the density of the foam glass and the lowest density is around 0.18 g/cm^3 when the content of Na_2HPO_4 is 2%.

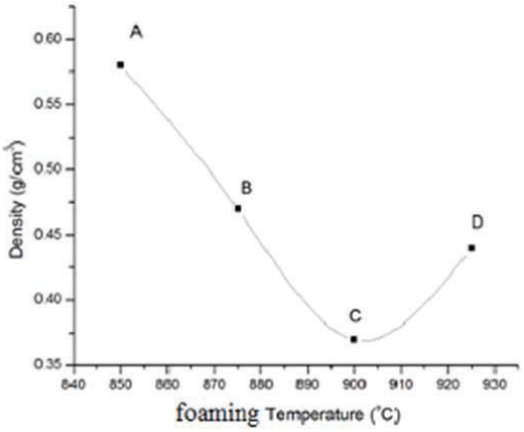


Figure 4. Densities of the foam glass produced at different foaming temperatures

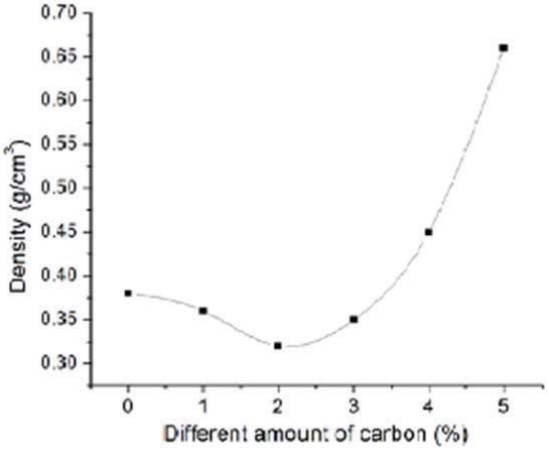


Figure 5. Densities of the foam glass produced at different amounts of carbon

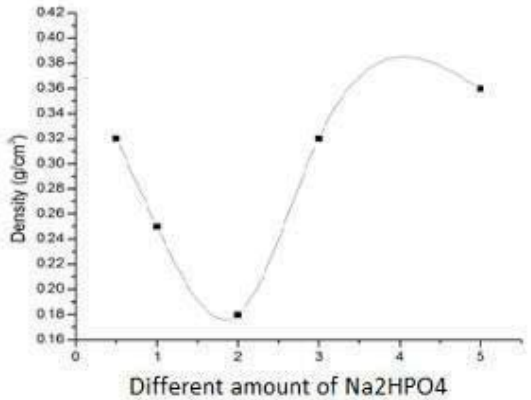


Figure 6. Densities of foam glass produced with different amount of Na_2HPO_4

The main objective of this project is to produce lightweight foam glass using mixed color waste glass as raw material. Herein, after developing and optimizing the sample preparing method, heating process and formulation, mixed color waste glass is used as raw material to produce foam glass. The mixture of 3% $CaCO_3$, 12% sodium silicate solution, 2% carbon, 2% Na_2HPO_4 and various mixture of different color waste glass are used as raw material. The densities of the obtained foam glasses are shown in Figure 7. The results show that the densities of foam glasses produced using different mixed color waste glass as raw material are around 0.17-23 g/cm^3, which prove that mixed color waste glass also can be used as raw material to produce foam glass. The pictures and microscope images of the obtained foam glass are shown in Figure 8. The pore sizes are small and uniform, which are in the range of 0.05 to 0.2 mm.

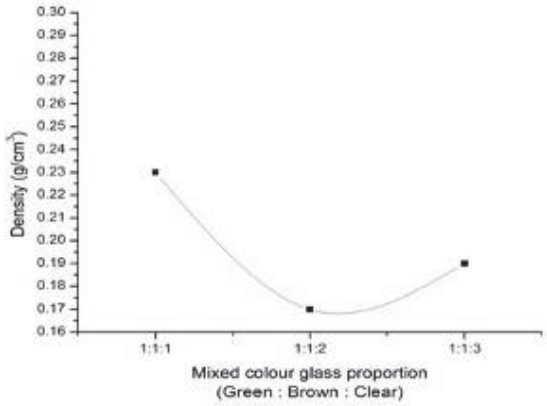
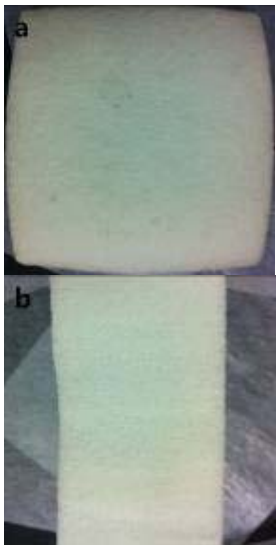


Figure 7. Densities of foam glass produced with different amount mixed color waste glass



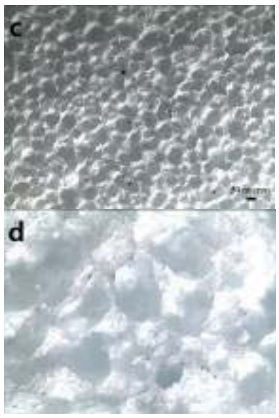


Figure 8. The pictures (a. top view & b. cross view) and microscope images (c. 1×50 & d. 3×50) of the obtained foam glass

The feasibility of industrial production is very important for this project. Herein, the foam glass scale up production has been studied. Bigger and thicker samples (300 g, 7.0 × 7.0 × 3.0 cm, and 1.8 Kg, 20.0 × 20.0 × 2.0 cm) are produced. However, there are unusual big holes (Figure 9) present in the middle of the big samples, which are attributed to non-uniform temperature in the samples. To solve this problem, a steel tray with many small holes is designed and the samples are put on the tray during the heating process. The temperatures of the bottom and top parts of the samples should be uniform.

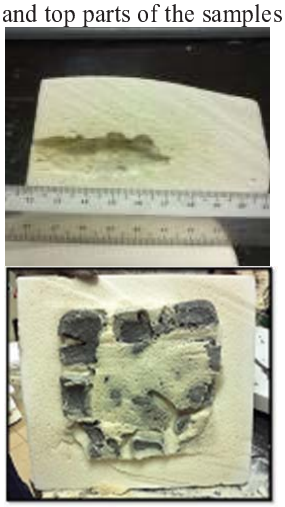


Figure 9. Photographs of bigger and thicker foam glass samples

Additionally, the heating rate from pre-heating temperature to foaming temperature is further optimized to make the temperature uniform in the big samples. Normally, the big holes disappear and pore sizes become more uniform using low heating rate (1 – 2 °C), but the densities of the foam glasses become higher. Based on the results, the heating rate of 3 – 4 °C is suitable to produce big and thick foam glass samples with uniform pore size and low density (Figure 10).



Figure 10. Photograph of thick foam glass sample

The energy consumption is the main cost of foam glass production. It is very important to reduce the foaming temperature and energy cost. In this project, we have reduced foaming temperature by adding a special additive. Adding 1.5% of this additive can reduce the foaming temperature from 900 °C to 800-825 °C. The pore sizes of the big foam glass prototypes are uniform and the densities (0.2 – 0.3 g/cm^3) are low. Figure 11 shows some photographs of big foam glass prototypes produced at 800-825 °C. The big foam glass prototypes have been cut to regular shape using a milling machine. After cutting, the foam glass samples are decorated with wall papers or hard papers, which probably can be used as celling board or partition wall (Figure 12).



Figure 11. Big foam glass prototypes produced at 800-825 °C

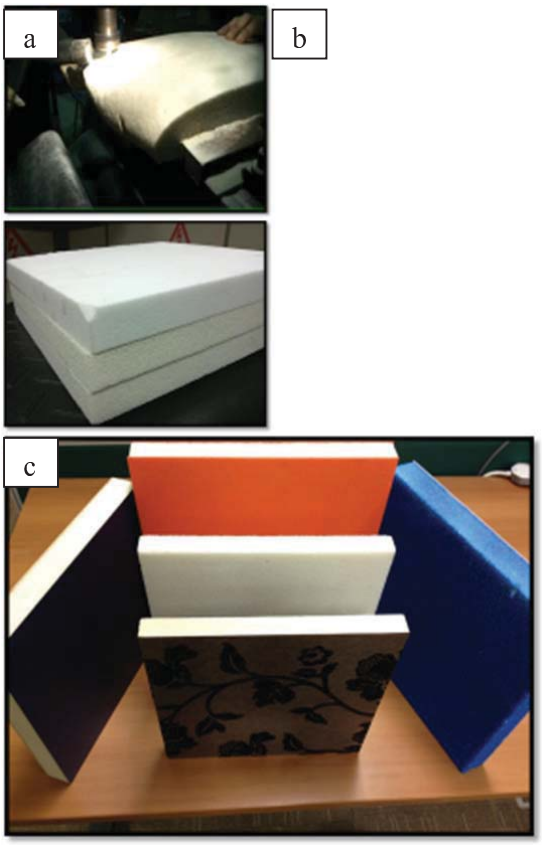


Figure 12. Photographs of (a) sample shaping process, (b) shaped samples and (c) samples after decoration

The big foam glass prototypes are tested after all the parameters have been optimized. The big foam glass prototypes show high porosity (85 – 93%), small pore size (0.05 – 0.5 mm), low density (0.18 – 0.25 g/cm^3), low thermal conductivity (0.068 W/m°K), relative high sound adsorption coefficient (0.5) and high compressive strength (1.5 – 2.0 MPa), which are comparable with commercial foam glass.

CONCLUSION

In this project, an eco-friendly and energy saving method has been developed to produce foam glass using waste glass as raw material. After optimizing the formulation and processing parameters, high quality foam glass is produced at relative low temperature (800 - 825 °C). The possibility of using mixed-colour waste glass as the raw materials to produce high quality foam glass is also investigated. The results prove that low-grade mixed-colour waste glass can be used to produce high quality foam glass. Scale-up production trials are conducted to produce foam glass prototypes with dimensions of bigger than 40 × 40 × 10 cm. The obtained foam glasses show small pore size (0.05 – 0.5 mm), high porosity (88 - 93%), low density (0.18 – 0.25 g/cm^3), low thermal conductivity (0.068 W/m°K), relative high sound adsorption coefficient (0.5) and high compressive

(1.5 – 2.0 MPa) & flexural strength (0.8 – 1.2 MPa), which are comparable with commercial foam glass. The recycle of waste glass as foam glass would help to increase the solid waste recycling rate in Singapore and extend the lifespan of the Pulau Semakau landfill.

ACKNOWLEDGMENT

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INTEGRATED OPTIMAL CONTROL FOR HVAC AND LIGHTING DEVICES FOR A SATISFACTORY INDOOR ENVIRONMENT AND MINIMAL POWER CONSUMPTION

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ABSTRACT

The objective of this study is to establish an integrated control algorithm for all HVAC and lighting devices of an office, which gives the real-time (based on the weather condition) operation instructions leading to minimal device power consumption and a satisfactory indoor environment. The test case is an open-plan office in North Taiwan. The penalty function method of optimization design is applied, a control algorithm is developed, and a computer program is written for the test case based on the algorithm. The weather parameters are input to the computer, and the computer program finds the optimal control parameters of devices and shows the parameters on the monitor for occupants' reference. A comparison is made between the conventional way of operation and the optimal way of operation for the devices. And the results show that the total HVAC and lighting energy consumption is reduced by 21% with the optimal way of operation, and this is achieved without sacrificing the environment qualities.

INTRODUCTION

Building energy consumption is a major part of total energy consumption in the modern society, and the major portions of building energy consumption are HVAC and lighting. While the energy resources are getting more and more scarcely, building energy conservation has become an important issue currently.

However, energy conservation strategies can be popularized only if satisfactory indoor environment qualities are maintained. The environment qualities considered in this study include thermal comfort, indoor air quality, and lighting quality.

New products contribute to substantial results in building energy conservation, such as energy efficient bulbs. They can effectively reduce lighting energy consumption without changing users' habits. Careful selections of building materials and proper building design can also achieve energy conservation. Examples include using high reflectance materials or paints on exterior walls and roofs, and proper shading of windows. On the other hand, daily operations of building equipment are also major factors affecting energy consumption and environment qualities. Two buildings with the same design and function can have very different amounts of energy consumption under operations of different users. Good design without good operation cannot effectively achieve the goal of reducing energy consumption while maintaining environment qualities.

In this study the emphasis is on office energy consumption and environment qualities. In an open-plan office, usually the lights, shades, air conditioners, fans, and etc. are operated by the users intuitively or based on a preset schedule. The environment qualities may satisfy the users' needs, but the energy consumption may not be minimized in general.

There are more than one ways to maintain a satisfactory indoor environment, but different ways correspond to different amounts of HVAC and lighting power consumption. For example, when the air conditioner is on but the indoor fans are off, the set-point temperature is set to 25^{o}C to maintain a satisfactory thermal comfort level. On the other hand, if the indoor fans are turned on and the set-point temperature is raised to 27^{o}C, the thermal comfort level remains the same, and the air conditioning power consumption is substantially reduced.

At a given weather condition, if the controller can find the way that consumes the least amount of electric power among the different ways to maintain a satisfactory indoor environment, then the long-term energy saving benefits may be very significant. This requires the controller to take into account all the relevant HVAC and lighting devices in the office, and apply an integrated control strategy for these devises. Currently this kind of control strategies are not in practice, and the common office buildings still have substantial potential for energy consumption reduction.

The objective of this study is to establish an integrated control algorithm for HVAC and lighting devices of an open-plan office, which gives the real-time (based on the weather condition) operation instructions leading to minimal device power consumption and a satisfactory indoor environment.

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DEFINITION OF THE PROBLEM

The Office And Its Devices

The test case is an open-plan office, 13m wide, 9m deep, and 3m high. The office locates in North Taiwan (24.8° North), and it is at the 1st floor of an office building. The external windows face west. The office is divided equally into three zones according to the distances from the external windows. Zone A is adjacent to the windows, Zone B is the next, and Zone C is farthest from the windows. Zone C has doors to the air-conditioned hallway. Each zone has four cubicles.

The office's air conditioner is a part of the central air conditioning system of the building, and the capacity is sufficient for the maximal cooling need in summer. Two window sashes are operable, and the maximal ventilation area is 1.0m^2. All windows are equipped with operable shades. Light guiding films are attached to upper parts of the windows, which deflect the sunlight to the ceiling for lighting purpose. The parts of windows with light guiding films are called light guiding windows, and the rest parts are called normal windows. Each of the three zones has it's own lighting switch, and the lighting power density can be adjusted between 0 and 9.0 W/m^2. Moreover, each cubicle is equipped with a personal fan. The operable devices mentioned above are all considered in the control algorithm.

Standards Of Environment Qualities

The lighting quality is measured with the illuminance L. When L≧500 lux at the desk level, it is considered a satisfactory lighting environment. Moreover, in order to avoid glare, when the direct sunlight flux is greater than 100 W/m^2 on the window surfaces, the shades of the normal windows should be closed to block the sunlight.

Thermal comfort level is measured with the PMV index [1], and the satisfactory range is set to be -0.5≦PMV≦0.5. The indoor air quality is measured with the CO2 concentration C_{CO2}, and the satisfactory range is C_{CO2}≦1100ppm [2]. CO2 itself is not toxic under the common concentration level in an office, but its concentration can serve as an index of the concentrations of other pollutants. A satisfactory indoor environment means that the above requirements are satisfied.

Basic Assumptions

In order to simplify the problem at this stage, the relevant physical quantities in the office are considered to be in quasi-equilibrium states during work hours. Every morning the HVAC devices are activated if necessary so that the thermal environment becomes within the preset comfort range before the work hours. After that the changes of relevant physical quantities are very slow, and the office environment is considered in equilibrium at each moment during work hours.

Definition Of Parameters

In this study the parameters are divided into three categories: constants, independent variables, and dependent variables.

- Constants

The constants include building geometry parameters, physical properties of building materials, physical properties of air and water vapor, and etc. The following is a list of these constants:

A_W：Area of the normal windows: 22.2 m^2

A_G：Area of light guiding windows: 3.0 m^2

A_M：Area of the inner surfaces of the floor, walls, and ceiling

A_A, A_B, A_C：Floor areas of Zone A, B, and C, respectively. All are 39.0 m^2

a_{AC}：Humidity ratio at the AC outlet. When the outdoor air humidity ratio is greater than 0.01 kgH2O/kgAir, a_{AC} = 0.01 kgH2O/kgAir; otherwise a_{AC} is equal to the outdoor air humidity ratio.

a_H：Humidity ratio of the hallway air: 0.01 kg H2O/ kg Air

C_{AC}: The COP value of the AC system: 3.0

c_{Pa}：Constant pressure specific heat of air: 1005 J/kgK

d_a：Density of air at 1 atm, 25°C: 1.2 kg/m^3

e_V：Enthalpy of vaporization of water: 2.5*10^6 J/kg

f_{DA}：Daylight factor of Zone A：2.5% (Daylight factors of Zones B, and C are negligible)

q_S：Luminous efficacy of sunlight: 100 lm/W

q_L：Luminous efficacy of artificial lights: 70 lm/w

r_C：Visible reflectance of the ceiling: 0.7

T_H：Temperature of the hallway air: 25°C

T_{AC}：Temperature at the AC outlet: 15°C

t_G：Visible transmittance of the light guiding films: 40%

U_W：Heat transfer coefficient of the normal windows

U_G：Heat transfer coefficient of the light guiding windows

U_M：Heat transfer coefficient between the indoor air and the surfaces of the floor, walls, and ceiling

- Independent variables (**X**)

These variables include weather variables, device control parameters (which are to be optimized), and number of occupants. For each device control parameter, a set of discrete possible values are defined. The following is a list of these variables:

X_1: Temperature of outdoor air (^oC)
X_2: Humidity ratio of the outdoor air (kg H2O/kg Air)
X_3: Energy flux of diffuse sunlight (W/m^2)
X_4: Energy flux of direct sunlight measured on the external surface of the windows (W/m^2)
X_5: Pressure difference (outdoor pressure minus indoor pressure) (Pa)
X_{6A}, X_{6B}, X_{6C}: Numbers of occupants in Zone A, B, and C, respectively (X_{6A}=0, 1, 2, 3, or 4, same for Zone B, and C)
X_{7S} : Set-point temperature of the AC system (X_{7S} =25, 26, 27, or 28^oC)
X_8: Total ventilation area of the windows (X_8=0.00, 0.25, 0.50, 0.75, or 1.00 m^2)
X_{9W} : Shade position of the normal windows: X_{9W} =0% means the shades are fully closed, and X_{9W} =100% means the shades are fully opened. (X_{9W} = 0%, 50%, or 100%)
X_{9G} : Shade position of the light guiding windows. (X_{9G} = 0%, 50%, or 100%)
X_{10A}, X_{10B}, X_{10C}: Lighting electric power density of Zone A, B, and C, respectively (X_{10A}=0.0, 3.0, 6.0, or 9.0 W/m^2, same for Zone B, and C)
X_{11A}, X_{11B}, X_{11C}: Power of one personal fan when its cubicle is occupied. Each personal fan is off when its cubicle is not occupied. (X_{11A}=0, 30, or 60 W, same for Zone B, and C)
X_{12}: Clothing level (X_{12}=0.5, or 1.0 clo)
X_{13}: Average temperature of the surfaces of the floor, walls, and ceiling (^oC). It is actually affected by other variables, but the rate of change is slow, and it is treated as an independent variable in this study, like a weather parameter.

- Dependent variables (**Y**)

These variables vary with independent variables, and, based on the quasi-equilibrium assumption, there are functional relationships between the independent variables and the dependent variables: **Y**=**Y**(**X**)

Y_1: Power consumption of the AC system (W)
Y_2: Power consumption of the lighting system (W)
Y_3: Average temperature of the indoor air (^oC)
Y_4: Average humidity ratio of the indoor air (kg H2O/ kg Air)
Y_5: Air change rate through the windows and doors (kg/s)
Y_{6A}, Y_{6B}, Y_{6C}: Wind speeds around the occupants in Zone A, B, and C, respectively (m/s)
Y_{7A}, Y_{7B}, Y_{7C} : Illuminance at Zone A, B, and C, respectively. (lux)
Y_{8A}, Y_{8B}, Y_{8C} : Mean radiant temperature at Zone A, B, and C, respectively (^oC)

Control Goal

With a given weather condition and number of occupants, find the combination of control parameters (of all the HVAC and lighting devices) leading to a minimal device power consumption and a satisfactory indoor environment. Display the combination of control parameters for occupants' reference.

CONTROL ALGORITHM

Based on the goal described above, the problem can be treated as a constrained optimization problem: the design parameters to be optimized are all the control parameters for the HVAC and lighting devices; the design goal is to minimize the total power consumption of the devices under the constraint that the indoor environment qualities have to be within the preset ranges.

Definition Of The Cost Function

The above design problem can be solved by the "penalty function method". Firstly a cost function C is defined to measure the performance of each design. The smaller the cost function value, the better the design. In this case the cost function C is defined as

$$C = Y_1 + Y_2 + P$$

where P is the penalty function. When the indoor environment qualities are within the preset ranges, let P=0. When the indoor environment qualities are farther away from the preset ranges, let the value of P be larger (and let the magnitude of P be much larger than that of (Y_1+Y_2)).

Control Optimization

If a combination of control parameters leads to an unsatisfactory indoor environment, the large value of P enlarges the value of C, and therefore this combination of control parameters does not lead to the minimal value of C. Among the combinations of control parameters leading to satisfactory indoor environment (P=0), there exists one combination that leads to the minimal value of C. This combination of control parameters maintains a satisfactory indoor environment and uses the minimal amount of power (Y_1+Y_2), and thus it is the optimal combination.

In other words, the combination of control parameters that corresponds to the minimal value of C is the optimal combination. Because each control parameter only has several discrete possible values, the number of possible combinations of control parameters is finite, even though it may be a large number. The control system collects real time information about the weather, wall temperatures, and number of occupants from the sensors, calculates the cost function value for every possible combination of control parameters, and finds the combination leading to the minimal cost function value. This optimal combination of control parameters can be shown on a monitor for occupants'

reference, or sent to the HVAC and lighting devices for direct control. The frequency of control parameter adjustment does not have to be high. In this study the adjustment is done once every hour.

IMPLEMENTATION OF THE ALGORITHM

Functional Relationships Between Dependent And Independent variables: **Y**=**Y**(**X**)

The cost function is a function of **X** and **Y**. In order to obtain the relationships between the cost function C and the control parameters at given weather conditions, the relationships between the dependent variables **Y** and the independent variable **X** have to be obtained first.

Building energy simulation software is popular in industry and research applications. This kind of software uses energy conservation principle to calculate the indoor environment status and the energy consumption. The functional relationships between the input parameters (independent variables) and the output parameters (dependent variables) are implemented in the software. Some examples of the software are EnergyPlus, eQuest, and DeST. In the software, the control parameters of HVAC and lighting devices are set based on a specified schedule. For example, the lights are on from 8am till 6pm on weekdays, and the AC is on from 7am till 6pm, and the set-point temperature is 25°C. This is suitable for estimating the energy consumption with conventional HVAC and lighting control, but not suitable for our test case with real-time optimization control. In this study, the software is not adopted. Instead, the functional relationships are derived based on energy conservation principle, mass conservation principle, and the quasi-equilibrium assumption. The following is a brief description of the derivation.

- Ventilation rate of the windows and the doors (Y_5)

First assume the windows are at the windward side. When the windows are open, the outdoor air flows into the office and the indoor air flows to the hallway. Based on fluid dynamics, the relationships among the ventilation rate, indoor-outdoor pressure difference, and ventilation area is

$$Y_5=C_D \cdot X_8 \bullet (2 \bullet d_a \bullet \mid X_5 \mid)^{1/2}$$

in which C_D is the drag coefficient, and C_D=0.6; the air density d_a=1.2 kg/m^3

Other than the ventilation rate above, the building has an infiltration rate Y'$_5$ (For the office in this study, the infiltration rate is roughly estimated as 0.05kg/s) :

$$Y_5= C_D \cdot X_8 \bullet (2 \bullet d_A \bullet \mid X_5 \mid)^{1/2} + Y'_5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

When the windows are at the leeward side, the derivation is similar and is not described here.

- Lighting power consumption (Y_2):

Based on the definitions, the total lighting power consumption is expressed as：

$$Y_2= A_A \bullet X_{10A} + A_B \bullet X_{10B} + A_C \bullet X_{10C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

- Average indoor air temperature (Y_3) and average indoor air humidity ratio (Y_4):

First assume the windows are at the windward side. Based on energy conservation, the energy (sensible and latent) brought in by the outdoor air, minus the energy carried away by the air flowing to the hallway, plus the solar heat gain, plus the heat transferred from the outdoor air to the indoor air through the window, plus the heat transferred from the building structures to the indoor air, plus the heat emitted from the occupants and the equipment, should equal zero at equilibrium, and thus：

$$Y_5 \bullet [c_{Pa} \bullet (X_1-Y_3)+e_V \bullet (X_2-Y_4)] + X_{7Q} \bullet [c_{Pa} \bullet (T_{AC}-Y_3)+e_V \bullet (a_{AC}-Y_4)] + U_W \bullet A_W \bullet (X_1-Y_3) + U_G \bullet A_G \bullet (X_1-Y_3) + U_M \bullet A_M \bullet (X_{13}-Y_3)+E_R +E_P = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

in which X_{7Q} is the air flow rate of the AC system, E_R is the solar heat gain：

$$E_R=(X_3+X_4) \bullet A_W \bullet S_W(X_{9W})+(X_3+X_4) \bullet A_G \bullet S_G(X_{9G})$$

and S_W is the solar heat gain coefficient of the normal windows, and it is a function of the shade position X_{9W}；S_G is the solar heat gain coefficient of the light guiding windows, and it is a function of the shade position X_{9G}. E_P is the heat emission rate of occupants and equipment：

$$E_P=300 \bullet (X_{6A}+X_{6B}+X_{6C})+Y_2 + (X_{11A}X_{6A}+X_{11B}X_{6B}+X_{11C}X_{6C}) \text{ (Watt)}$$

Assume that there is no water evaporating to the indoor air, and the water vapor emitted from occupants is neglected. Thus we have：

$$Y_5 \bullet (X_2-Y_4) + X_{7Q} \bullet (a_{AC}-Y_4) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

When the AC is off, X_{7Q}=0, and Y_3 and Y_4 can be solved from Equations (3) and (4). When the AC is on, the average indoor air temperature (Y_3) is equal to the AC set-point temperature (X_{7S}), and Y_4 and X_{7Q} can be solved from Equations (3) and (4). When the windows are at the leeward side, the derivation is similar and is not described here.

- HVAC power consumption (including the power consumption of the AC system and the personal fans)：

$$Y_1= X_{7Q} \bullet [c_{Pa} \bullet (Y_3-T_{AC})+e_V \bullet (Y_4-a_{AC})]/C_{AC} + (X_{6A} \bullet X_{11A}+X_{6B} \bullet X_{11B}+X_{6C} \bullet X_{11C})$$

- Wind speeds around occupants：

Wind speed affects the thermal comfort level. Assume that the air inside the cubicles is almost stationary when personal fans are off, and the air moves around the occupants at a very low speed 0.1m/s due to thermal convection. When the personal fan is on, assume the relationship between the average wind speed Y_6 and the fan power X_{11} is as the following.：

$Y_{6A}=0.1+0.01 \cdot X_{11A}$ (m/s) (same for Zone B, and C)

- Mean radiant temperature Y_8

MRT also affects the PMV index. MRT can be estimated using (X_1, X_3, X_{9W}, X_{9G}, Y_3). The process is not described here. A reference can be found in ASHRAE HVAC Applications A54.1

- Illuminance Y_7：

Assume that the light energy enters through the light guiding films is divided into two parts: 70% of the light goes to Zone A, and 30% goes to Zone B. Thus the luminance of Zone A, B, and C can be written as:

$$Y_{7A}= X_{10A} \cdot q_L + X_{9G} \cdot X_4 \cdot A_G \cdot q_S \cdot t_G \cdot r_C \cdot 70\%/A_A + (1/2) \cdot X_{9W} \cdot X_3 \cdot q_S \cdot f_{DA}$$

$$Y_{7B}= X_{10B} \cdot q_L + X_{9G} \cdot X_4 \cdot A_G \cdot q_S \cdot t_G \cdot r_C \cdot 30\%/A_B$$

$$Y_{7C}= X_{10C} \cdot q_L$$

When a combination of control parameters is chosen at a given weather condition (**X** determined), all the dependent variables (**Y**) can be solved using the above equations, and then the cost function value (a function of **X** and **Y**) can be obtained.

The Computer Program

A computer program is written based on the above framework. The input parameters are keyed in to the computer, and then the computer finds the optimal control parameters, and shows it on the monitor for users' reference. A weather sensor network is to be established to feed data to the computer program.

RESULTS

A Snap Shot

The following is an example to show the benefits of the integrated control algorithm. The weather condition is as the following: the outdoor temperature is 26°C, relative humidity is 60%, diffuse sunlight flux is 200W/m^2, direct sunlight flux is 0 W/m^2, outdoor pressure is 6 Pa higher than the indoor pressure, and the average temperature of the inner surfaces of the building structures is 25°C. Table 1 shows the comparison between the conventional way and the optimal way of operation for the devices.

With a conventional way of operation, the windows are closed and the ventilation rate is low, and the ventilation doesn't have significant effects on cooling. The indoor air is heated by the sunlight, and the heat emission from equipment and occupants. The indoor thermal comfort index PMV exceeds the upper limit (0.5), and thus the AC needs to be turned on to maintain a satisfactory thermal comfort level.

On the other hand, the optimization control program suggests the following operation: turned off the AC, fully open the operable windows for a large amount of ventilation, and use shades (not including the shades beside the open sashes) to block the sunlight to reduce the heat gain. Both ways of operation satisfy the environment quality requirements, but the optimal way of operation uses 2,230W less power.

Table 1
A comparison between the conventional way and the optimal way of operation for the devices

		Conventional way	Optimal way
Control parameters	AC	On, Set 25°C	Off
	Operable windows	Fully closed	Fully open
	Shades of normal windows	100% open	50% open
	Shades of light guiding windows	100% open	0% open
	Lighting power densities (Zone A,B,C)	6, 9, 9 (W/m^2)	6, 9, 9 (W/m^2)
	Clothing	0.5 clo	0.5 clo
Environment qualities	Lighting	OK	OK
	Thermal comfort	OK	OK
	Indoor air quality	OK	OK
Power consumption	AC	2,230 W	0 W
	Lighting	940 W	940 W

Annual Performances

In order to estimate the long-term performances of the integrated control algorithm, the hourly weather data of Taipei of the Typical Meteorological Year is used. The hourly weather data is substituted into (X_1, X_2, X_3, X_4, X_5). Work hours are 8am~6pm on weekdays. The average temperatures of the inner surfaces of the building structures (X_{13}) are roughly estimated using a correlation between the structure temperatures and the weather data.

A conventional way to operate the HVAC and lighting devices is based on a preset schedule.

Assume that the office is fully occupied during work hours (X_{6A}=X_{6B}=X_{6C}=4) The HVAC is turned on whenever the indoor air temperature exceeds 26C during work hours, and the set-point temperature is 26^{o}C (X_{7S}=26^{o}C). The windows are always closed (X_{8}=0). The shades of the normal windows are open in the morning (X_{9W}=100% during 8am~12noon); and closed in the afternoon (X_{9W}=0% during 12noon~6pm). The shades of the light guiding windows are always open (X_{9G}=100%). The lights are always on during work hours (X_{10A}=X_{10B}=X_{10C}=9.0W/m^{2}). No personal fans are utilized (X_{11A}=X_{11B}=X_{11C}=0). The clothing value is 0.5 from May till October (X_{12}=0.5 clo), and 1.0 from November till next April (X_{12}=1.0clo).

As for the optimal way of operation, the optimal control parameters for each work hour are found based on the hourly weather data. The procedure is repeated for every work hour of the year, and the total energy consumption is obtained. (non-work-hour operations are considered to be identical for both ways of operation)

The annual energy consumption of the office under the above operation schemes are calculated using a computer program. The results show that the annual HVAC and lighting energy consumption is reduced by 21% with the optimal operation scheme, and this is achieved without sacrificing the environment qualities.

CONCLUSIONS

This study aims to establish an integrated optimization control algorithm for all the HVAC and lighting devices in an office. The goal is to reduce the total energy consumption of the devices while maintaining a satisfactory indoor environment. The test case is an open-plan office in North Taiwan. The penalty function method of optimization design is applied and a cost function is defined. The smaller the value of the cost function, the better the design. The cost function is evaluated for all possible combinations of control parameters, and the combination leading to the minimal value of the cost function is found. This combination is the optimal combination of the control parameters for the devices. It maintains a satisfactory indoor environment by using a minimal amount of energy. A computer program is written for the test case based on the above algorithm. The weather data are input to the computer, and the computer program finds the optimal control parameters and shows the parameters on the monitor for occupants' reference. A comparison is made between the conventional way of operation and the optimal way of operation for the devices, and the results show that the annual HVAC and lighting energy consumption is reduced by 21% with the optimal way of operation, and this is achieved without sacrificing the environment qualities.

REFERENCES

1. ISO 7730
2. ASHRAE Standard 62.1

ENERGY SAVING POTENTIAL FOR RETROFFITING MIXED-USE BUILDINGS IN SINGAPORE: DEVELOPING BEST PRACTICES AT NTU CAMPUS

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ABSTRACT

In Singapore, existing buildings are the overwhelming percentage of a building stock that consumes approximately 31% of all electricity generated [Building and Construction Authority, 2010]. Therefore, existing buildings play a critical role in improving overall sustainability and efficiency for Singapore. Singapore and the Building Construction Authority (BCA) has made this a priority by targeting to have 80% of the existing building stock Green Mark certified by 2030 [Building and Construction Authority, 2010]. Therefore, the main objective of this study is to explore energy saving potential in an existing building with proven energy efficiency measures (EEMs).

The building from this case study represents a typical mixed-use NTU facility with office space, teaching space and lab spaces. The building parameters are from the building management system (BMS) and site surveys. Those parameters were used to create a building energy model using Google SketchUp and NREL's OpenStudio. The baseline model was calibrated to match the monthly energy consumption profile, and to accurately represent the building equipment and operation patterns. A series of retro• t strategies – including envelope optimization, operation schedule adjustment and advanced lighting system – were applied to the calibrated baseline model to determine annual energy savings potential. The simulation results indicate that the proposed EEMs can achieve approximately 36.34% energy savings compared to the calibrated baseline model.

INTRODUCTION

In Singapore, it has been standard practice to demolish and rebuild buildings after only 10 to 15 years of operation [Building and Construction Authority, 2010]. This pattern is not sustainable for the future as it requires extensive amounts of materials that are becoming increasingly rare and wastes the embedded energy of constructing the original building. As such, building design will need to account for over 50 years of operation and multiple refurbishment projects, such as replacing windows, installing new chiller plant equipment, and improving the building control system. Besides the previous sustainability argument, the Building and Construction Authority (BCA) claims that each year new construction projects account for only 5% of the building stock in Singapore [BCA, 2010], indicating that existing buildings are responsible for the majority of energy consumption associated with buildings in Singapore.

To assist Singapore developing into a sustainable metropolis, there must be a guideline to aid decision-making in future retrofit projects. To date, there have not been many retrofit projects in Singapore that attempt to overhaul the entire building. The National Renewable Energy Laboratory (NREL) claims that a top-to-bottom renovation of a building is the best way to reduce building operating costs.

The primary objective of this study is to create a calibrated energy model for block N3.2 that houses the School of Mechanical and Aerospace Engineering at NTU. Once calibrated, the energy model can simulate different retrofit measures in order to determine the best options, since simulation is more cost effective than a trial-and-error approach with installing and monitoring equipment.

SIMULATION METHODOLOGY

The energy simulation methodology was similar to that of a new building, meaning the building geometry was created using architectural drawings and cooling loads were generated using occupancy and equipment behaviour tied to weather data that includes solar radiation and changes in temperature. For this study, the geometry was created using Google SketchUp Pro, then imported into OpenStudio to conduct the energy simulation.

The building model was "calibrated" to match the billed energy use within an allowable tolerance, which is usually 5 – 10%. This process is typically more involved than new construction building simulation projects because of the extra effort required to gather building and occupancy data. The team made multiple site visits to most accurately represent space use, the mechanical equipment, and to set up sensors to record temperature and light levels.

The NTU Office of Development and Facilities Management (ODFM) are supportive of this work and collaborated by providing building construction and operation data as needed.

Appropriate retrofit measures were applied to the calibrated model. Each EEM was modelled individually to determine their impact on energy consumption over an entire year.

Building description

The study building is Block N3.2, which houses the School of Mechanical and Aerospace Engineering at

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the Nanyang Technological University (NTU) campus. The building has a total floor area of 14,472 m^2 and was completed in 2005 (Figure 1). Space uses within this building mainly include staff offices, researcher rooms and teaching/research laboratories.



Figure 1 Block N3.2 building (14,477 m^2)

The conditioned area in this building is 12,214 m^2, which is served by the HVAC system through Variable Air Volume (VAV) type Air Handling Units (AHUs) and Fan Coil Units (FCUs) serving the different zones of the building. Cooling is provided by chilled water from a central chiller plant located on campus. This chiller plant system also serves two other buildings with a total floor area of 22,610 m^2. BTU meters are installed for each building to monitor the monthly cooling energy usage. The physical characteristics of the building are given in Table 1.

Model development

The building geometry was created by importing architectural drawings of floor plans into Google SketchUp Pro and then extruding each floor plan up to the height of a building story. Once the building "shell" was complete, other components of the external façade, such as windows and skylights, were incorporated. The final 3-D geometry is shown in Figure 2.

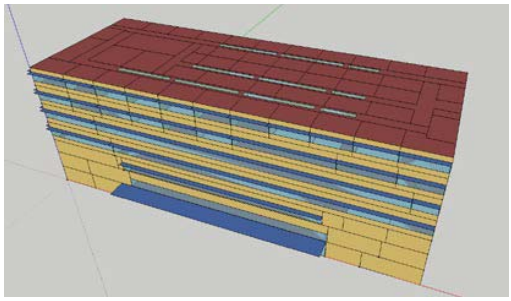


Figure 2 3D geometry of N3.2 in SketchUp

The geometry was imported into OpenStudio (NREL 2012), which is graphical software developed by NREL and US Department of Energy (DOE) to support whole building energy modelling. Using EnergyPlus as the simulation engine, inputs such as weather files and equipment specifications are used in conjunction with building geometry to simulate energy consumption.

Table 1
Physical Characteristics of Building Model

COMPONENT	DESCRIPTION
Location	Nanyang Technological University campus
Type of building	7 stories, total building height = 28m, rectangular shape
Space type	University academic building: mainly office and lab usage
Gross floor area	14,472 m^2
Envelope	External wall assembly: 20 mm cement/sand plaster, 100 mm RC, 20 mm cement/sand plaster; External wall U = 3.24 W/m^2·k
	Roof assembly: 50 mm sand/cement screed, 50 mm polystyrene foam board, 150 mm RC, Roof U-value = 0.59 W/m2·k
	Floor: 150 mm concrete, Floor U-value = 1.74 W/m^2·k
	Window: U-value = 1.8 W/m^2·k, SHGC = 0.29, VLT = 0.54
	WWR = 0.5 for north and south wall, overall WWR = 0.33
HVAC	VAV without reheat
	13 AHUs, and 46 FCUs
	Setpoint temperature: 23 °C for office, 25 °C for other spaces
	4 Chillers, each with 450 RT capacity, 2 in operation and 2 standby. Chiller plant system efficiency = 0.75 kW/RT, supply chilled water temperature = 7 °C, return water temperature = 12 °C

Data collection

Building simulation requires a diverse set of inputs ranging from building construction materials, lighting /equipment power density, occupants and system operation schedules, and HVAC systems. The accuracy and integrity of these data are critical to the accuracy of the predicted performance.

In order to obtain accurate building data, the research team collaborated with NTU Office of Development and Facilities Management. The main source of data includes:

- Architectural drawings used to identify geometries and layouts, story height and window areas
- Tender drawings and documents used to identify construction (roof, external wall, windows) assembly details and property values
- Electrical design plans used to calculate lighting power of different space in the building

- Billing history with monthly electricity and cooling energy consumption

Hourly cooling demand data and system operation schedules were obtained from the Building Management System (BMS) in N3.2. Multiple site visits were made to confirm that building envelope and equipment are as indicated on plans. In addition, the number of occupants and schedules were also obtained during the site visit and interviews with occupants.

Model input

The typical meteorological year (TMY) data of Singapore developed by DOE was used as the input weather file in the annual simulation. The input parameters for building envelope can be found in Table 1. The U-value of the external wall and roof are 3.24 W/m^2·k and 0.59 W/m^2·k, respectively. The window to wall ratio (WWR) is 0.5 for north and south walls. The window glass is double-glazed with a U-value of 1.8 W/m2·k and solar heat gain coefficient (SHGC) of 0.29.

Outdoor airflow rate was set as 0.01 m^3/s·person, and infiltration rate was defined as 0.15 ACH using OpenStudio default settings. The rooms with same internal loads and operation schedules are assigned to one specific space type. After reviewing all the documents and information from site visits, eight space types were identified:

- Staff office
- Researcher room
- Computer lab
- Classroom
- Teaching/research lab
- Restroom
- Corridor for second story
- Corridor for other stories

The detailed input for each space type including lighting power density (LPD), equipment power density (EPD), and occupant density are summarized in Table 2.

Table 2
Input Details for Lighting, Equipment and People

SPACE TYPE	LPD (W/M^2)	EPD (W/M^2)	OCCUPANT DENSITY (PAX/M^2)
Staff Office	12	16.00	0.07
Researcher Room	12	16.00	0.33
Classroom	12	16.00	0.43
Computer lab	12	30.00	0.30
Teaching/ Research Lab	12	30.00	0.14
Corridor	5	3.98	0.10
Corridor-2nd floor	2.5	3.98	0.10
Restroom	10	3.98	0.10

Operation schedules for lighting, equipment and people are shown in Figure 3, Figure 4, and Figure 5, respectively. Staff office and corridors on the second story use the same operation schedules and are thus represented as staff office. Other spaces using the same schedules are represented as researcher room.

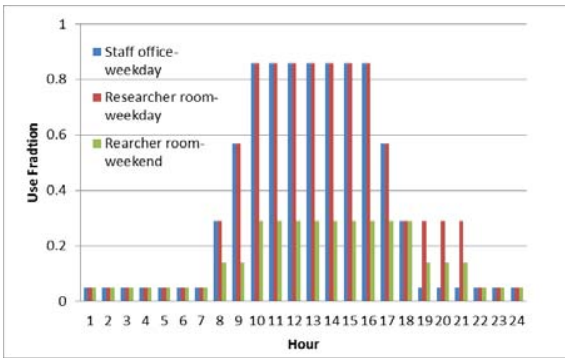


Figure 3 Operation schedule of lighting

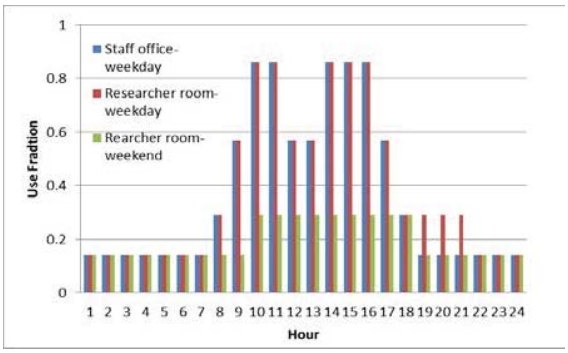


Figure 4 Operation schedule of equipment

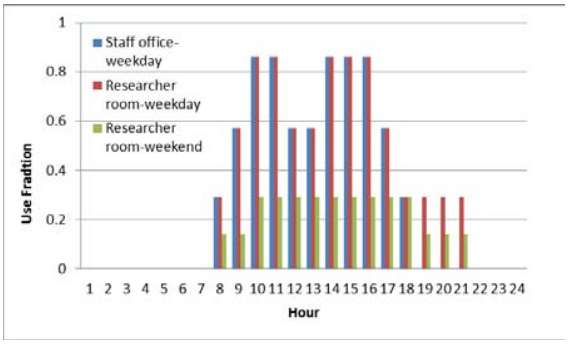


Figure 5 Operation schedule of people

All the rooms served by the same AHU are integrated into one thermal zone, and other rooms served by FCUs in the same room were grouped into one thermal zone. Using this organization method, the building model consists of 23 thermal zones. The room temperature cooling set point is 25°C for all spaces in the building except staff offices, which is set to 23°C because of agreement and implementation issues. The operation schedules for AHUs and FCUs are shown in Table 3.

Table 3
Operation Schedules for AHUs and FCUs

AHU/ FCU	SERVICE SPACE	WEEK DAY	WEEKEND
AHU 1-2	Staff office	24 hours	24 hours
AHU 3-6	Researcher rooms	06:00-21:00	06:00-21:00
AHU 7-9	Teaching Lab /classroom	07:00-19:00	Off
AHU 10-13 & FCUs	Research Labs	07:00-22:00	07:00-22:00

Model calibration

Model calibration is an essential task to ensure that the architectural, mechanical and electrical systems are properly modelled to accurately simulate building energy performance. Considering the availability of monthly utility data, monthly calibration was applied in this study. Monthly simulated energy consumption should be within 10% of metered monthly data and 5% of annual data. Figure 6 shows that the calibrated baseline model matches well with the actual energy usages in 2012. The annual difference between simulated and actual energy consumption was -3.53%. Black error bars denote ±10% deviation from monthly metered data.

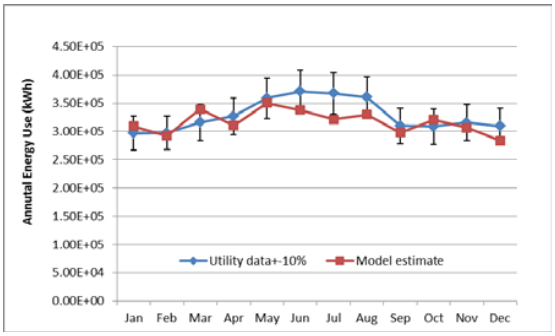


Figure 6 Monthly energy consumption comparison between model estimate and real utility data (±10%)

RESULTS AND DISCUSSION

Energy consumption analysis

An evaluation was performed from the baseline model to explore the potential of energy savings in the building. Monthly energy end-use is shown in Figure 7. It was found that the cooling is the dominant energy end use for each month in a year, and cooling consumption in summer (May – Aug) season is slightly more than that in winter season (Nov – Jan). This trend is consistent with Singapore weather conditions.

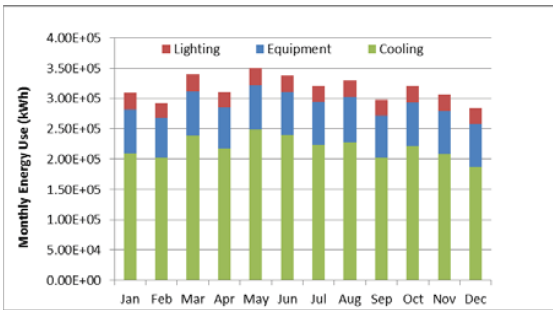


Figure 7 Breakdown of monthly building energy consumption

The annual energy consumption breakdown for the building model is shown in Figure 8, which shows that the biggest component of annual energy usage is cooling (69%), followed by equipment (23%) and lighting (8%).

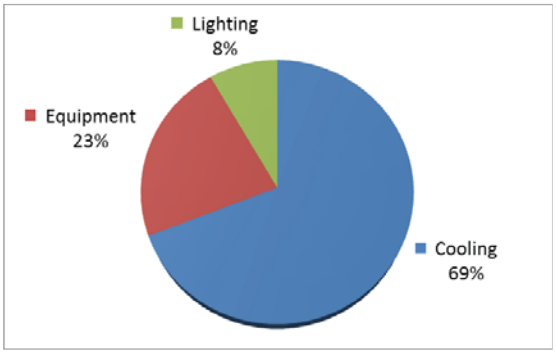


Figure 8 Breakdown of annual building energy consumption

In addition, an analysis of the sensible cooling load was made to identify the components that contribute most to sensible cooling load using the ability to generate detailed load output information for each zone from EnergyPlus. Sensible load components due to heat gain are shown in Figure 9.

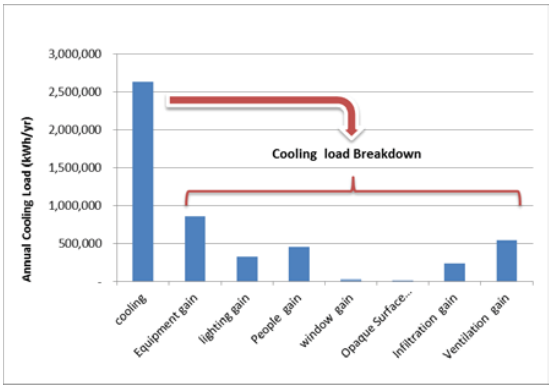


Figure 9 Annual sensible cooling load breakdown

It can be seen that window gain and opaque surfaces have minimal influence on cooling demand, mainly because the windows have a good U-value (1.8) and SHGC (0.29). In contrast, internal heat gain from

equipment contributes most to cooling demand, followed by ventilation, people, lighting and infiltration. Apart from the sensible cooling demand, the latent cooling demand also contributes to cooling load. A comparison of annual sensible and latent cooling energy use is shown in Figure 10.

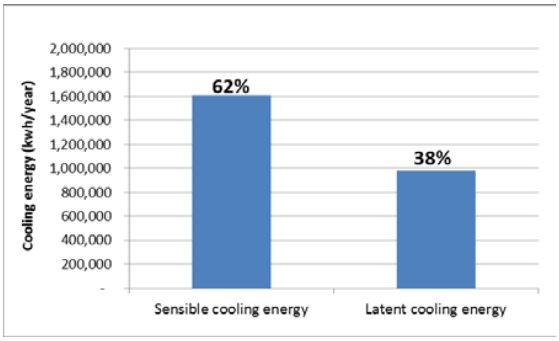


Figure 10 Annual sensible and latent cooling energy

As shown in Figure 10, the sensible and latent cooling loads are responsible for 62% and 38% of total cooling energy, respectively. This is similar to the typical values of 60% and 40% experienced in tropical climates [Listijono, 2010].

Evaluation of EEMs

Based on the energy end-use and cooling load breakdown analysis, several energy efficient measures (EEMs) were proposed and investigated. Each EEM was modelled individually to determine their impact on energy consumption over an entire year. A list of EEMs and model input information are given in Table 4.

Changing set point temperature and operation schedule does not require any economic investment in the existing building system. Therefore, this measure is usually considered as the first implementation option. As mentioned above, the cooling temperature was set at 25°C for most spaces in the building except staff office in the second story due to implementation issues. In addition, the air con serving staff office operates 24 hours per day to remove noxious emissions from renovated floor carpets. Therefore, EEMs were proposed to raise the set point in offices to 25°C (O1) and turn off the air con during unoccupied hours (O2) for staff offices. The simulation result shows that EEM-O1 and EEM-O2 can achieve 0.35% and 1.14% of total energy consumption, respectively.

Enclosure system upgrades can provide a significant opportunity to achieve energy efficiency in office buildings (Loftness V., 2012). In this study, EEMs include adding roof insulation, green roof, green wall, upgrading windows, and enhancing building air tightness. The input parameters for greenery systems were obtained from a study conducted by Wong et al., 2009. The simulation results show all EEMs except upgrading building air tightness yield insignificant savings of less than 1%. This result is consistent with the annual cooling load breakdown analysis, indicating windows and opaque surfaces are insignificant contributors to sensible cooling demand. Two studies by Karaguzel and Lam concluded that reducing infiltration could be the most effective energy-saving strategy for existing buildings. However, this study was conducted in the United States and further investigation concerning application in tropical regions still needs to take place. In our study, the effect on energy consumption of reducing the infiltration rate from 0.15 ACH to 0.10 ACH was analysed. From Figure 12 it can be seen that envelope infiltration rates have significant effect on space cooling energy with 2.16% reduction.

There are a variety of simple and inexpensive measures to improve the efficiency of lighting systems, including the use of more energy efficient lamps, installation of occupant sensors and day lighting sensors. The first EEM (L1) is to replace current T8 fluorescent lamps with more efficient T5 lamps. The input value for lighting power density was based on improvement of lumen per watt. Typically, T8 and T5 lamps generate 80 lm/W and 100 lm/W, respectively. This EEM can achieve 3.17% saving of annual building energy consumption. EEMs like occupant sensors and daylight sensors do not yield significant savings (0.62% and 0.27%, respectively).

Plug and equipment loads are the biggest electricity consumsers in existing buildings. This is important since the heat generated from operating equipment becomes a cooling load to be addressed by the HVAC system. Therefore, reduction of equipment load can simultaneously reduce primary electricity consumption to operate as well as secondary electricity consumption to provide cooling. Two EEMs were proposed in this study to address this issue: improving equipment efficiency and including on/off controllers to turn off office equipment when not in use. Results show that 20% improvement in energy efficiency for equipment can yield 4.49% savings in annual building energy use. In comparison, installation of on/off controllers for office equipment yields more energy savings (8.54%). These results indicate that a significant amount of electricity can be saved during night hours when staff and students leave campus.

Conventional air conditioning (AC) systems have limited control of sensible cooling and latent cooling capacities. An integrated HVAC system is proposed to handle the building sensible and latent loads separately in order to achieve energy savings. One such system is a Dedicated Outdoor Air Systems (DOAS) that allows fresh air to be dehumidified and sensibly cooled independently before being supplied to the space. If more sensible cooling is required, then return air from the space can be passed over a cooling coil and recirculated back to the space, saving fan energy use. The DOAS modelled in this study used a medium temperature chiller plant with

Table 4
List of EEMs Description and Model Input

SYSTEM		EEMS	PROPOSED VALUE	BASELINE VALUE	SAVING %
Operation and schedule	O1	Increase setpoint by 2 °C	Setpoint 25°C for office	Setpoint 23 °C for office	0.35%
	O2	Reduced aircon hours (late start, early shutdown)	AHUs serving staff office: 06:00 - 21:00	AHUs serving staff office: 24 hours	1.14%
Lighting	L1	Replace current T8 with T5	LPD = 9 W/m^2 for staff office, researcher room, classroom and labs; LPD = 3.75 W/m^2 for corridor; LPD = 1.88 W/m^2 for second story corridor; LPD = 7.5 W/m^2 for restroom	LPD = 12 W/m^2 for staff office, researcher room, classroom and labs; LPD = 5 W/m^2 for corridor; LPD = 2.5 W/m^2 for second story corridor; LPD = 10 W/m^2 for restroom	3.17%
	L2	Install occupancy sensors to control interior lighting	LPD = 9.6 W/m^2 for staff office, researcher room, classroom and labs; LPD = 4 W/m^2 for corridor; LPD = 2 W/m^2 for second story corridor; LPD = 8 W/m^2 for restroom	LPD = 12 W/m^2 for staff office, researcher room, classroom and labs; LPD = 5 W/m^2 for corridor; LPD = 2.5 W/m^2 for second story corridor; LPD = 10 W/m^2 for restroom	0.62%
	L3	Install daylighting sensors in perimeter zones	LPD = 4 W/m^2 for corridor LPD = 8 W/m^2 for restroom	LPD = 5 W/m^2 for corridor LPD = 10 W/m^2 for restroom	0.27%
Envelope	E1	Add roof insulation	Roof U = 0.49 W/m^2·k (k_{ins} = 0.03 W/m·K)	U = 0.59 W/m^2·k	0.20%
	E2	Add green roof	Roof U = 0.493 W/m^2·k (R value = 0.36 m2*K/W)	U = 0.59 W/m^2·k	0.44%
	E3	Add green wall	Ext Wall U = 0.5 W/m^2·k (R value = 0.36 m2·K/W)	U = 3.24 W/m^2·k	0.97%
	E4	Replace windows	Double pane, U value = 1.3 W/m^2·k, SHGC = 0.20, VLT = 0.54	Double pane, U value = 1.8 W/m^2·k, SHGC = 0.29, VLT = 0.54	0.49%
	E5	Reduce infiltration by enhancing air tightness through window and door	ACH = 0.10	ACH = 0.15	1.21%
Equipment load	P1	Add advanced on/off control of office equipment	LPD & EPD fraction during off hours = 0.15	LPD & EPD fraction during off hours = 0.00	8.54%
	P2	Purchase energy efficient office equipment	Office EPD = 12 W/m^2	Office EPD = 16 W/m^2	4.49%
HVAC chilled water	H C1	Upgrade HVAC equipment	Medium temperature chiller plant, CHWS = 12°C, DOAS System: Sensible Load Efficiency = 0.45 kW/RT L-DEC: Latent Load Efficiency = 0.365 kW/RT	Low temperature Chiller plant, system efficiency = 0.75 kW/RT, CHWS = 8°C	12.99%

an efficiency of 0.45 kW/RT to meet sensible loads and an advanced liquid desiccant system (L-DEC) with an efficiency of 0.365 kW/RT to meet latent loads. This EEM generates significant energy savings of 12.99% in a year for the whole building. Annual building energy use savings are shown in Figure 11. For example, all EEMs associated with improving lighting were implemented and the resulting energy savings are shown in the "Lighting" bar. If all EEM packages were implemented, the total annual energy savings would be 36.34%.

The energy savings discussed in this section are summarized in Table 4. It is better for building owners to know each EEM separately so that they can combine them into system packages according to their ability and budget.

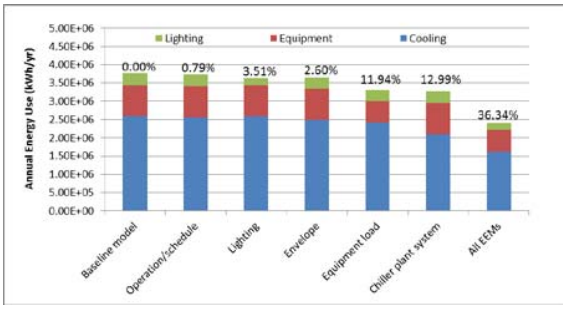


Figure 11 Energy saving for each EEM system

FUTURE WORK

The future work for this study includes economic analysis via net present value (NPV) approach to account for cost savings and energy savings over the life cycle of the EEM. Additional analysis shall include sensitivity analysis for calibration and energy savings potential. Comfort analysis should also be included to better contextualize indoor thermal quality.

CONCLUSION

The results from this study indicated that the internal heat gains from plug loads and lighting loads significantly affect the annual cooling load for this mixed-use building. The most effective measures are simultaneously reduced equipment, lighting loads with a Dedicated Outdoor air System. The whole building energy simulation methodology highlights the importance of studying the interactions of multiple EEMs. For example, the integrated approach shows that the sum of each measure is only 31.83% energy savings relative to the baseline where greater energy savings is achieved when each measure is modelled together.

This study has also provides the opportunity to discuss opportunities for energy efficiency with ODFM. For example, the average cooling load profile for a typical term weekday and holiday (Figure 12) shows similar consumption levels although there is less occupancy and activity during the holiday time. Perhaps the mixed-use facility has even greater energy savings potential, beyond 36.34% if the seasonal load profiles are adjusted.

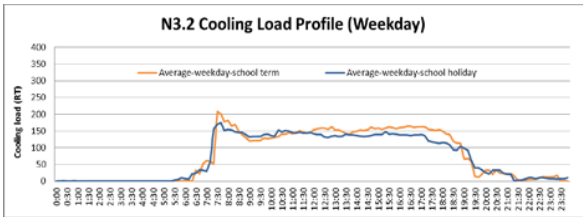


Figure 12 Average cooling load profile for typical term weekday and school holiday

The findings from this study are promising; the existing mix-use facility can achieve up to 36.34% energy compared to the current model. The results of the study will also be used to inform the building users and the facilities management department of opportunities to save energy.

ACKNOWLEDGMENT

The authors would like to acknowledge the Office of Development and Facility Management at NTU for their cooperation with obtaining building data and specifications.

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ENERGY-SAVING TECHNOLOGIES INCORPORATED IN LOW-CARBON OFFICE BUILDING LOCATED IN TOKYO

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ABSTRACT

This paper describes the energy-saving technologies incorporated in a low-carbon office building located in Tokyo. The air-conditioning system that combines a centralized system and heat pump package systems reduces energy consumption. The ductless air-conditioning system reduces material usage and keeps floor height to a minimum (3.5m) while securing a maximum ceiling height (3.17m) by combining with a full flat slab. The measurement results demonstrate that COP of the air-conditioning system is high and that the ductless air-conditioning system can prevent drafts from occurring in the occupied zone. The building also employs an energy-saving lighting system utilizing indirect lighting in addition to standard downward lighting. This system reduces energy consumption while making the indoor luminous environment bright and comfortable. Measured energy consumption for the lighting was 6.8 W/m^2, which is about half of that for standard office buildings in Japan. Annual CO_2 emissions for the whole building were around 37.5 kg-CO_2/(m^2•year), which is a 62.5% reduction compared to standard office buildings in Tokyo.

INTRODUCTION

Approximately one-third of the total CO_2 emissions in Japan are emitted from the building and construction sector. As the proportion of these emissions is increasing, finding ways to further improve the energy-saving performance of buildings is an important theme. This paper describes the energy-saving technologies introduced in a low carbon office building in Tokyo. An outline of the building is presented, followed by an outline of, and report on the performance verification for the air-conditioning system that combines a centralized system and heat pump package systems. The performance of the dustless air-conditioning system is verified in detail. An energy-saving lighting system utilizing indirect lighting is also introduced and verified. The annual electricity for the building as a whole is also reported.



Photo 1 Exterior View of the Building.

OUTLINE OF THE BUILDING

The building is an office building located in the city of Chofu in Tokyo, built as a research facility. It consists of one basement floor and five aboveground floors, with a total floor area of 8,913 m^2. Photo 1 shows the exterior view of the building. Figure 1 shows the floor plan of the office on a standard floor. Figure 2 shows the interior of the office space. Figure 3 shows a cross-section of the standard floor. The building is of reinforced concrete construction using full flat slabs with no beams. The skeleton shape of the exterior is a clear-cut flat slab (with a slab thickness of 330 mm) structure, with eaves protruding 1.15 m on the outside of the south

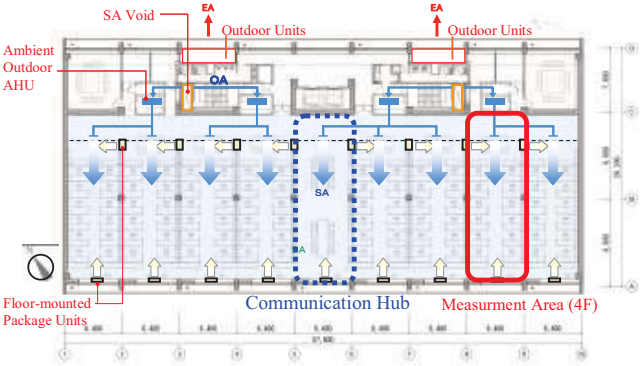


Figure 1 Plan of Standard Floor (3F to 5F).



Figure 2 Interior View of Office Space.

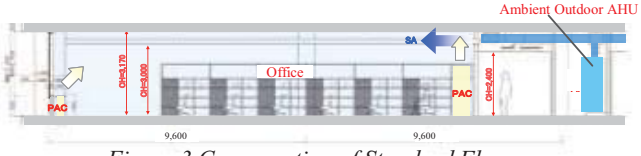


Figure 3 Cross-section of Standard Floor.

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windows that consist of single-sheet glass and venetian blinds. The resulting facade provides a balance between ensuring a good view and providing sunlight-blocking performance. In addition, as a measure to prevent cold drafts in the area around the windows in the wintertime, the return air for the perimeter indoor air-conditioning units is taken in from slits beneath the windows. The office area has no ceiling panel nor raised floor in order to conserve resources by keeping the use of interior materials to a minimum, and also with the aim of streamlining the construction and ensuring economic rationality. To ensure the sound absorbing performance of the ceiling, wood wool cement boards are placed at the boundaries between each span. Moreover, to provide the functions of a free access floor, wiring space is provided in the baseboard section beneath the shelves at the boundaries between spans to secure power and LAN wiring routes to individual booths. Eliminating the free access floor and using flat slabs for the ceiling made it possible to secure a ceiling height of 3.17 m despite the low floor height of 3.5 m.

OUTLINE OF AIR-CONDITIONING SYSTEM

The air-conditioning system for the building consists of air-source heat pump chillers (HP chillers) + outdoor air handling units (AHUs) and separate-distributed heat pump package air conditioners (task package systems), with the centralized system for base operation (ambient outdoor AHUs) and the task package systems for intermittent operation (Hiromoto et al., 2011 and 2012-2013). Table 1 shows the specifications for each HVAC system in the standard floor offices. HVAC is provided by four ambient AHUs on each floor and one task package system for the interior and perimeter of each span (see Figure 1). In addition to processing the outside air, the ambient outdoor AHUs also process the base indoor load (heat produced by lighting and by common office equipment) as well as humidification and dehumidification. They detect the indoor temperature and control the supply temperature. They are also equipped with CO_2 concentration control and variable air volume control that is capable of cooling with outside air during intermediate seasons, and a ductless air-conditioning system that discharges supply air from the ambient outdoor AHUs along the ceiling. The task package for each span has a single outdoor unit to control the interior unit and the perimeter unit, providing integrated control for the temperature setting, air volume, and on/off control.

UTILIZATION OF DUCTLESS AIR-CONDITIONING SYSTEM

The ductless air conditioning system uses the flat slab surface of the ceiling to supply air from the interior to the perimeter without the use of ducts. The system uses the Coanda effect, in which the planar airflow

Table 1 Specification of Each HVAC System.

	Type	Cooling capacity [kW]	Heating capacity [kW]	Air volume [m³/h]
Ambient AHU (values per span)	Compact floor-mounted	10.0	8.5	305～610
Interior Package Unit	Floor-mounted	7.0	7.5	1,200
Perimeter Package Unit	Floor-mounted	7.0	7.5	1,080

Table 2 Calculation Conditions for CFD.

Turbulence model	Standard k-ε two-equation model
Finite difference scheme	MARS
Room temperature	26°C
Supply air outlets	Size: 1.12×0.03 m, Air volume : 700 m³/h Air velocity: 5.787 m/s Turbulence intensity: 10% Turbulence length scale: 0.003m Supply air temperature: 16°C
Internal heat	Set at the height from 0 through 1m

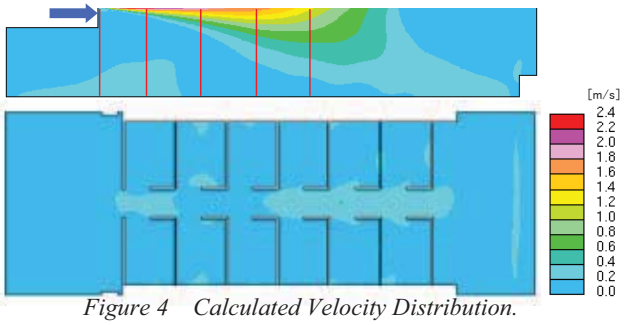


Figure 4 Calculated Velocity Distribution. (Central Section, Fl + 1.1m)

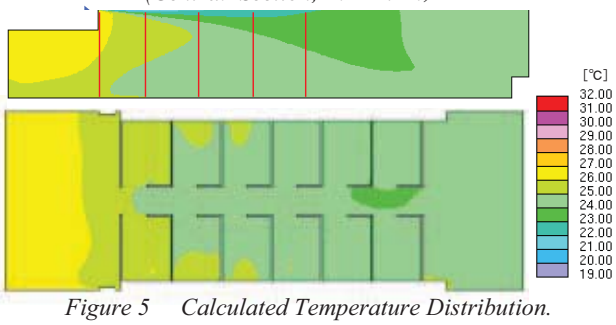


Figure 5 Calculated Temperature Distribution. (Central Section, Fl + 1.1m)



Photo 2 Mock-up Test of Ductless Air-conditioning System.

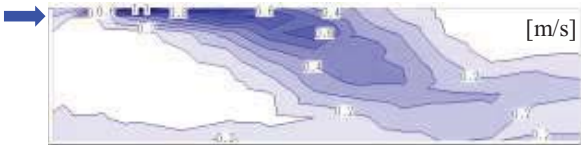


Figure 7 Measured Velocity Distribution by Mock-up Test. (Air volume: 610m³/h, supply air temp. diff. Δt=10°C)

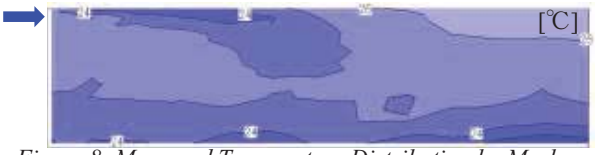


Figure 8 Measured Temperature Distribution by Mock-up Test. (Air volume: 610m³/h, supply air temp. diff. Δt=10°C)

from the supply slits flows along smooth, flat surfaces. This system conserves resources through the reduction of ducts, provides an ornamental effect through the use of slabs for an exposed ceiling, and reduces the floor height and provides an ample ceiling height.

While the ductless air-conditioning system offers major advantages, it was anticipated that drafts might occur during the cooling period, inconveniencing building occupants. This section describes the content of the studies conducted with these issues in mind, as well as the results of the performance verification conducted after the building was completed.

Study at the Planning Stage using Computational Fluid Dynamics (CFD)

Simulation by CFD was conducted to a standard span (W 6.4 m x D 18.6 m). Twelve individual booths (H = 1.4 m) and shelves to serve as boundaries between each span (H = 1.95 m) were modelled. Table 2 shows the conditions for calculation. The supply quantity of heat for the air-conditioning system was calculated from the air volume supplied to the standard span and the temperature differential with the air supply (ΔT = 10°), and this value was applied uniformly to the occupancy domain as the heat generated within the room.

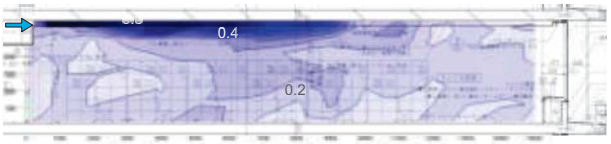
Figure 4 shows the results of calculated velocity distribution. These results confirm that, due to the Coanda effect, the supply air flows along the ceiling as it flows from the supply outlet, and that a separation of the flow from the ceiling surface occurs approximately 8-9 m from the supply outlet. It had been predicted that a residual air velocity of approximately 0.4 m/s would remain at around FL +1.5 m, but there was little planar diffusion of the air velocity distribution and it was limited to the central corridor area, so there is little likelihood that the airflow that separated from the ceiling surface and descended will reach directly to the individual seats. Figure 5 shows the results of calculated temperature distribution. Although a slight effect from the jet was observed in the central corridor sections, the temperature distribution was estimated to be small.

Study at the Planning Stage using Mock-up

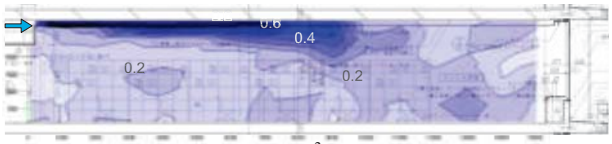
In the previous section, the thermal environment formed by the ductless air-conditioning system was predicted using CFD. Nevertheless, the airflows along the ceiling are generally complex, so it is difficult to predict them with high precision using CFD. For this reason, it was decided to produce an actual scale mock-up to confirm the air velocity and temperature distributions in the occupied zone. Photo 2 shows the mock-up apparatus. The test was conducted under various conditions using different supply air velocities and temperatures. Figures 7 and 8 show representative results of measured air velocity and temperature distributions with an air volume of 610 m^3/h and a supply air temperature differential of 10°C. The results of measurement were generally equivalent to the results of prediction using CFD. Even with a supply temperature differential of 10°C,

Table 3 Measurement Conditions.

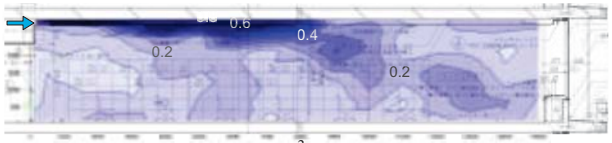
	Supply air velocity [m/s]	Supply air temperature difference ⊿t (Room temp. Tr- Supply air temp. Tsup)		
		0°C (Tsup= 26°C)	5°C (Tsup= 21°C)	10°C (Tsup= 16°C)
610m^3/h (Upper limit for CO_2 control)	5.7	Case 1-1	Case 1-2	Case 1-3
732 m^3/h (Upper limit for outdoor air colling)	6.8			Case 2-3
305 m^3/h (Upper limit for CO_2 control)	2.8			Case 3-3



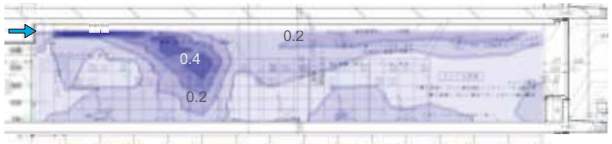
(1) Case 1-1 (610m^3/h, isothermal condition)



(2) Case 1-3 (610m^3/h, Δt= 10°C)

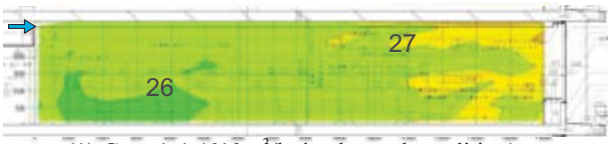


(3) Case 2-3 (732m^3/h, Δt=10°C)

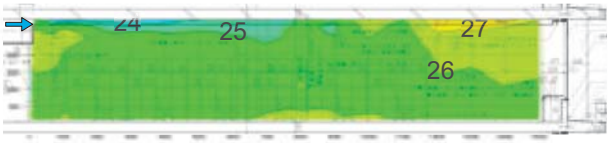


(4) Case 2-3 (305m^3/h, Δt=10 °C)

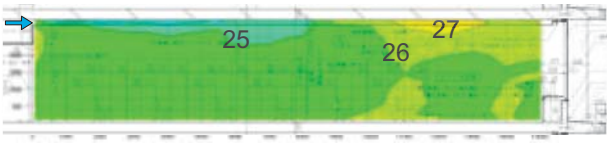
Figure 9 Velocity Distribution (Central Plane) [m/s]



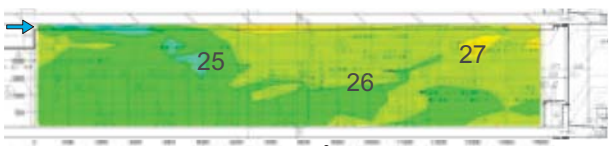
(1) Case 1-1 (610m^3/h, isothermal condition)



(2) Case 1-3 (610m^3/h, Δt= 10°C)



(3) Case 2-3 (732m^3/h, Δt=10°C)



(4) Case 2-3 (305m^3/h, Δt=10 °C)

Figure 10 Temperature Distribution (Central Plane) [°C]

it was predicted that there would be little danger of drafts occurring.

Performance Verification after Completion

In order to confirm the indoor thermal environment produced by the ductless air-conditioning system, the indoor air velocity and temperature distributions were measured after the completion of building. The measurements were conducted on July 11 and 12, 2011, before the occupants moved into the building. The second span from the east side on the 4th floor was selected as a representative span for measurement (Figure 1). Table 3 shows the measurement conditions. For these measurements, all of the separate package systems in both the interior and the perimeter were turned off. Three ambient outdoor AHUs that were not being measured were operated at a temperature setting of 26°C, and the one being measured was controlled so as to ensure the supply air velocity and temperature specified as measurement conditions.

The velocity and temperature distributions under various conditions at the supply outlet central section are shown in Figures 9 and 10, respectively. The velocity distribution results show that the velocity level in the occupied zone is approximately 0.2 m/s or less. A comparison of the temperature differential confirmed that, the lower the supply temperature differential was, the longer the flow along the ceiling. In the air volume comparison, there was little difference in the trend at an air volume of 732 m^3/h as compared to 610 m^3/h, but at 305 m^3/h it was confirmed that the airflow began to separate from the ceiling at a distance of approximately 4 meters from the supply outlet. This is considered to be because the reduced supply air velocity decreased the Coanda effect. However, the velocity level in the occupied zone was approximately 0.2 m/s, and the air temperature distribution was also within 1°C, so the level is not considered to pose problems for operation. The results of the temperature distribution revealed that the temperature level in the occupied zone in the work area was held to approximately 25-27°C.

Based on these results, it was confirmed that, with proper planning, the occurrence of drafts in the occupied zone could be prevented with this system.

AIR CONDITINING EFFICIENCY (COP)

An analysis was conducted to evaluate the coefficient of performance (COP) of the HP chiller connected to the ambient outdoor AHUs. Figure 11 shows the monthly-averaged system COP of the HP chiller, which includes the effects of the chiller and pumps. The system COP for the HP chiller is high in the winter and summer when the load throughput increases. In the intermediate seasons, however, the ambient system not only controls cooling with outside air but also provides natural ventilation, so the processed heat volume is small and ultimately the COP tended to be low. Figures 12 and 13 show the cooling and heating load ratio to the chiller capacity in summer and winter and the correlation with the

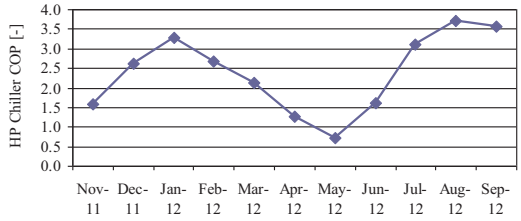


Figure 11 Monthly-averaged System COP of Air-source Heat Pump Chiller.

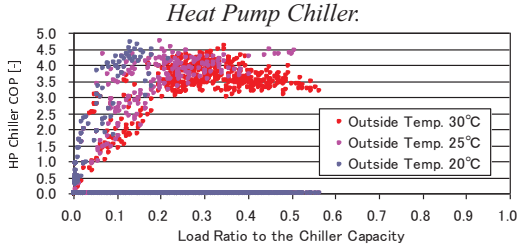


Figure 12 Cooling Load Ratio vs. COP of Air-source Heat Pump Chiller in Summer.

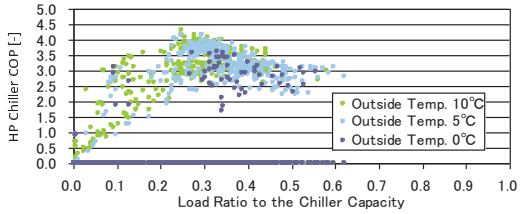


Figure 13 Heating Load Ratio vs. COP of Air-source Heat Pump Chiller in Winter.

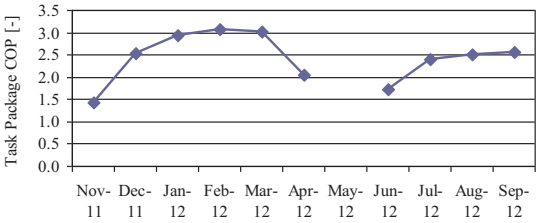


Figure 14 Monthly-averaged COP of Separate Package Air-conditioning Systems.

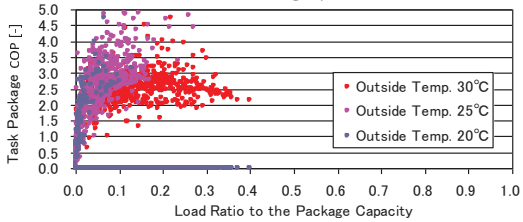


Figure 15 Cooling Load Ratio vs. COP of Separate Package Air-conditioning Systems in Summer.

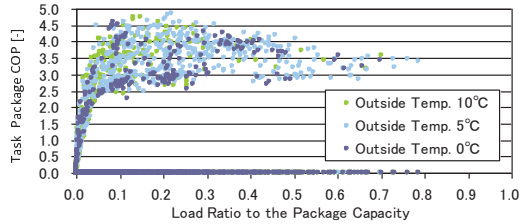


Figure 16 Cooling Load Ratio vs. COP of Separate Package Air-conditioning Systems in Winter.

system COP. In accordance with the main purpose of operation for the ambient system, a comparatively high load ratio of 40-50% was achieved in both summer and winter. Moreover, the properties of the air-cooled HP chiller were clearly evident: in summer the COP increased as the outside air temperature decreased, and in winter the COP increased as the outside air temperature increased.

Figure 14 shows the monthly-averaged COP for the task system. The COP increased in winter when the load throughput was great. During the intermediate seasons, particularly in May, there was no operating time, as the load could be processed using only the ambient system. Figures 15 and 16 show the correlation between the cooling and heating load ratio and COP of separate package system in summer and winter. Due to the fact that these packages were operating intermittently, the load ratios were low in both summer and winter, but overall the system was able to operate at a comparatively high COP.

TASK/AMBIENT LIGHTING THAT CONSIDERS PERCEIVED BRIGHTNESS

Background to Development

In Japan, task lighting is generally not used, and in many cases only ceiling lighting is used to make the desktop surface illuminance uniformly 750 lx. The combined use of task lighting and ceiling lighting to restrict the ambient lighting inside the room to 300 lx is an effective means of lowering electricity. However, offices that employ both task and ambient lighting are less bright due to the lower luminance of ceiling and wall surfaces, and for this reason little progress was made in increasing the use of these systems for many years. In the offices in this building, luminance images were estimated through simulations at the initial design stage, and indicators of perceived brightness were determined from these luminance images to realize task and ambient lighting that makes occupants feel that the space is bright.

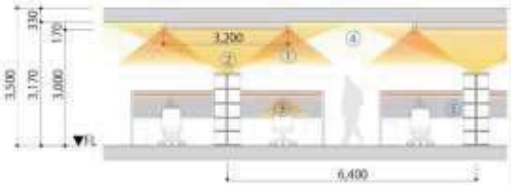
Outline of Lighting Systems

Figure 17 shows an outline of the lighting systems introduced to this building. The major feature of the lighting in these offices is the fact that fluorescent lights for ceiling indirect lighting have been provided above the high bookshelves in order to make occupants feel that the room is brighter. The desktop illuminance obtained from this indirect lighting alone is 70 lx, but the luminance of the ceiling surface is increased efficiently to make occupants feel that the room is comfortably bright. In addition, although uneven ceiling surface luminance has been pointed out as a disadvantage of indirect lighting, the difference in the materials of the flat slab direct ceiling and the wood wool cement boards was utilized to make it difficult to distinguish the unevenness in the luminance of the ceiling surface. To ensure floor visibility and safety, the lighting has been combined with direct lighting from fluorescent lights. The desktop illuminance obtained from this direct lighting alone is 300 lx. Prioritizing efficiency, louvers have not been used, but as the ceiling surface luminance has been increased through the use of indirect lighting to the level at which glare will not be produced, the Unified Glare Rating (UGR) value of the ambient lighting is 18, which is not high. LED lighting, which makes it possible to adjust the color temperature, was used for task lighting. Even with ambient lighting alone, there is sufficient illuminance for working on computers, so it was assumed that task lighting would be used primarily for work that involved reading and writing.

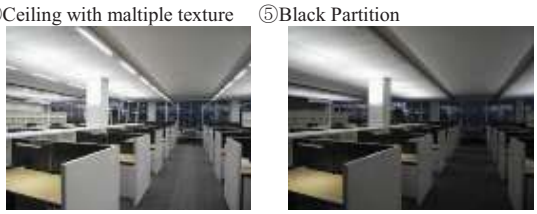
Study at the Design Stage

The aforementioned lighting systems were finalized after conducting a study using computer graphics to ensure that a feeling of perceived brightness could be kept as good level efficiently with a small amount of power (Figure 18). The study of perceived brightness was conducted using brightness impression indicators that were developed based on the subjective experiment results (Sakata, 2010). Specifically, the average value for the "Natural scale Brightness (NB)" (Nakamura, 2006), shown in a brightness image that takes into account the adaptive effect, was determined within a pitch angle of 0-20°, and the perceived brightness in the peripheral field was assessed in sedentary position.

At the interior design stage, the color of the partitions was finalized based on the indicator for perceived brightness. A mock-up of a single seat was placed in the laboratory and a luminance image was measured when a black partition and a white partition were provided to compare the perceived brightness and other indicators. The results showed that the indicator for "perceived brightness in the peripheral field"



①Direct Ambient Light ②Indirect Ambient Light ③Task Light
④Ceiling with maltiple texture ⑤Black Partition



(1) Direct Light and Indirect Light (2) Only Indirect Light (after 7:00pm)

Figure 17 Outline of the Lighting Systems.

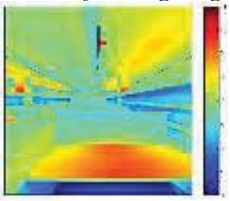


Figure 18 Brightness Image by Simulation.

when the black partition was used was higher than that when the white partition was used, as shown in Figure 19. This is because the adaptation brightness decreased when the black partition was used and the NB value in the peripheral field increased. Based on these results, black partitions were selected for the interior of the booths. Conversely, white partitions, which had received high values for the "perceived brightness of space" indicator, were selected for the color of the corridor partitions outside the booths.

Assessment after Completion

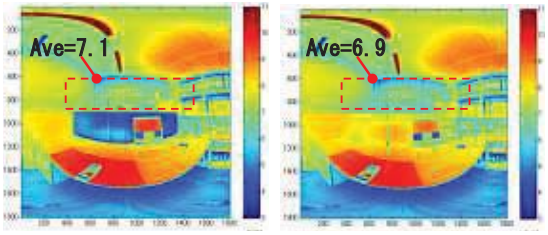
From the measured luminance images, a brightness image was converted and the perceived brightness indicator was determined. Figure 20 shows the results of a comparison between a standard office building and this building. Compared to the standard building, the perceived brightness indicator was low when the indirect lighting was turned off. When the indirect lighting was turned on, however, the perceived brightness indicator was greater than that of the standard building, confirming that the combined use of indirect lighting would improve the perceived brightness and help to reduce overall electricity.

At night, workers were encouraged to work using only ceiling indirect lighting from consideration for circadian rhythms. The direct lighting was turned off automatically three times each day at fixed intervals (7:00 p.m., 9:00 p.m., and midnight). This reduced the continuous use of direct lighting during the night, which had been observed immediately after the completion, and workers no longer forgot to turn off the lights. Moreover, although this office building did not have a function for regulating the color temperature of the ambient lighting, reducing the ambient lighting during the night increased the influence of color temperature regulation of the task lighting, as shown in Figure 21, and made it possible to reduce facial color temperature at night to 3,200 K, as shown in Figure 22. In addition, electricity was also reduced by automatically turning off the ambient lights during the lunch break.

The use rate of task lighting with respect to room occupancy was approximately 30-40% during the day and 50-65% at night. Converted into electricity, this represents usage of approximately 0.2 W/m^2. As shown in Figure 23, the results of measurement of the electricity for the ambient system were an average of 6.6 W/m^2 at peak times. With task lighting added in, this value becomes 6.8 W/m^2, which is about half or less of the illumination power at peak time periods for standard offices in Japan. Moreover, starting at 7:00 p.m., the use time of direct lighting is reduced in stages, so the electricity is further reduced.

OVERALL BUILDING ENERGY CONSUMPTION

An energy assessment was conducted in order to confirm the energy-conserving performance of the building. The assessment was based on the values measured during the one-year period following the completion, using the electricity and CO_2 emissions



(1) Black Partition (2) White Partition

Figure 19 Relationship between Partition Color and Brightness Perception (NB Value).

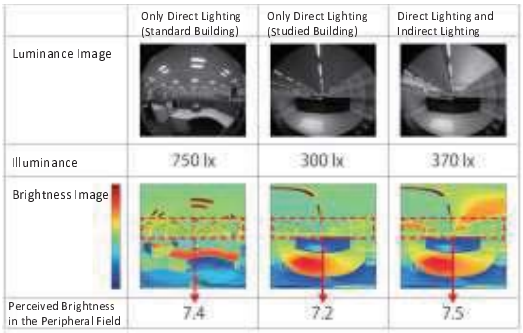


Figure 20 Comparison of Brightness Perception Calculated by Measured Brightness Image between the Studied Building and Standard Building.



Figure 21 Control of Color Temperature by Task Lighting.

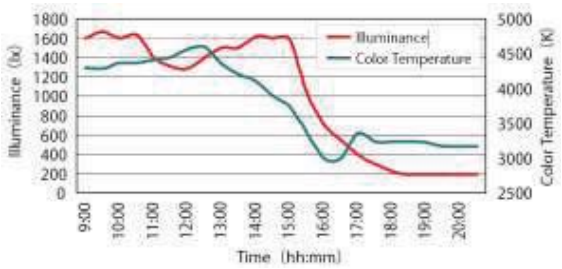


Figure 22 Daily Variation of Illuminance and Color Temperature.

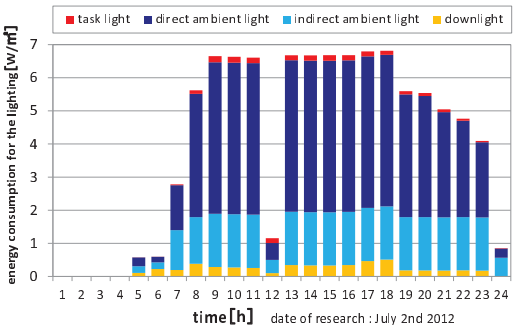


Figure 23 Measured Electricity Consumption for Lighting in the Office Space.

monitoring system constructed in this building. Figure 24 shows a comparison between the CO_2 emissions for a standard building and this building. For the standard building, the CO_2 emissions of 100 kg-CO_2/(m^2•year) for the standard office building in Tokyo in 2007 were supposed (Tokyo Metropolitan Government, 2007). This building is an all-electric building, and for the conversion from electricity to CO_2 emissions, the ratio of 0.382 kg-CO_2/kWh by the Global Warming Countermeasures Report System of the Tokyo Metropolitan Government was used. The measurements from April 2012 to March 2013 amounted to 37.5 kg-CO_2/(m^2•year), representing a reduction of 62.5% as compared to the standard building. Primary energy in this building was 959 MJ/(m^2•year), a 55.2% reduction as compared to 2141 MJ/(m^2•year) for the standard office building.

Figure 25 shows a composition of electricity in standard floor and common areas for each type of use. The standard floor accounted for approximately 38% of the electricity of the entire building, approximately 20% of which came from air-conditioning equipment. Electricity from the outlets on standard floors made up approximately 35%, slightly larger as compared to that from air conditioning and lighting. This is considered to be affected by the fact that the server computers in this building are dispersed throughout the offices. In addition, another characteristic of this building is that computers for large-scale computing are used, and the annual electricity in server rooms is large at around 18% of the total building electricity.

Figure 26 shows measured monthly electricity consumption for each item. There were few seasonal fluctuations in electricity for the server room, electrical outlets and lighting on standard floors. The seasonal fluctuations in monthly electricity were the result of fluctuations in HVAC load. Based on the results for the electricity of the HP chillers and task package systems, it was learned that the HVAC load was greater in winter than in summer. In the intermediate seasons, the electricity for Floor 3-5 office air conditioning (task packages and AHU fans) and HP chillers was low, confirming that the HVAC load was low.

Figure 27 shows annual electricity consumption for the whole building, in descending order. The maximum value for electricity demand was 444 kW (49.8 W/m^2), and it can be seen that the peak demand occurs in the winter. The average value during working hours on a working day was 18.4 W/m^2.

Figures 28 through 30 show the electricity for lighting, electrical outlets and air conditioning in the exclusively-owned office space as well as the maximum and average electricity consumed at each time on a working day during a representative month. The maximum value for lighting was 7.1 W/m^2 and the average value during working hours was 5.7 W/m^2. This value is approximately half that of an ordinary office in Japan, confirming the energy-saving performance of the lighting system introduced to this building. The maximum value for the office equipment outlets was 11.6 W/m^2, and the average value during working hours was 7.8 W/m^2, generally equivalent to the electricity of the electrical outlets in Building A with standard outlet electricity. There is a comparatively large outlet electricity of approximately 4 W/m^2 at night, due to such factors as the aforementioned computer servers that were placed in the office. The maximum value for air-conditioning power was 51.2 W/m^2, and the average value during working hours was 10.1 W/m^2. In terms of seasons, wintertime electricity is great in the morning when occupants turn on the task package systems, while in summer a constant thermal load is produced throughout the day. In the intermediate seasons, however, the thermal load is extremely small, so in some cases the task package systems are almost completely shut down, and it can be confirmed that the electricity is low for a long time. The fact that air-conditioning electricity for the ambient AHUs and task packages is extremely low during the intermediate seasons is a major factor contributing to energy conservation in the building.

CONCLUSION

This paper introduced the energy-saving technologies in a low-carbon building located in Tokyo and

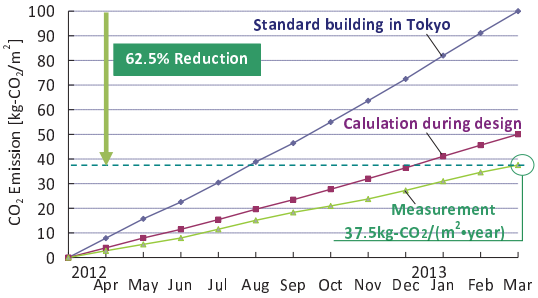


Figure 24 Measured CO_2 Emission and Predicted Value (from April 2012 through March 2013).

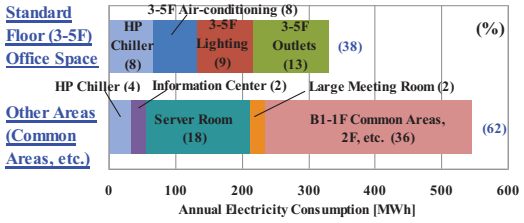


Figure 25 Measured Annual Electricity Consumption for Each Item.

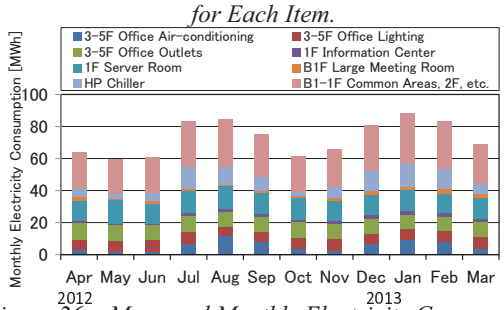


Figure 26 Measured Monthly Electricity Consumption for Each Item.

summarized the results of a performance verification of these technologies. The findings were as follows.

· Combining the ductless air-conditioning system that utilizes the Coanda effect with full flat slabs enables a ceiling-less design, which is effective for reducing resource, lowering floor height and ensuring an ample ceiling height. In addition, proper planning made it possible to prevent drafts from occurring in the occupied zones.

· For air conditioning, appropriate combination of a central system and separate package systems enables high COPs and energy conservation in all seasons.

· Planning of ambient lighting using indirect lighting based on perceived brightness made it possible to achieve lighting systems with a balance between the good light environment and reduced electricity.

· The measured CO_2 emissions were 37.5 kg-CO_2/(m^2•year), a reduction of 62.5% as compared to a standard office building in Tokyo. Primary energy consumption was 959 MJ/(m^2•year), a 55.2% reduction as compared to the standard office building.

· An analysis of electricity for lighting, electrical outlets and air conditioning revealed that lighting power and (particularly in the intermediate seasons) HVAC electricity were low, confirming that the introduced systems helped to reduce electricity.

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The authors would like to express their gratitude to Dr. Motoyasu Kamata, Professor Emeritus of The University of Tokyo, Dr. Satoshi Togari, Dr. Yoshinobu Arai, and Dr. Masaki Shioya of Kajima Technical Research Institute, and Mr. Jun Owada of Kajima Design, who provided valuable advice during this research. The authors are also grateful to those who cooperated in performing the measurements.

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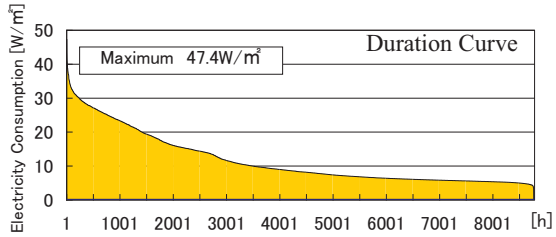
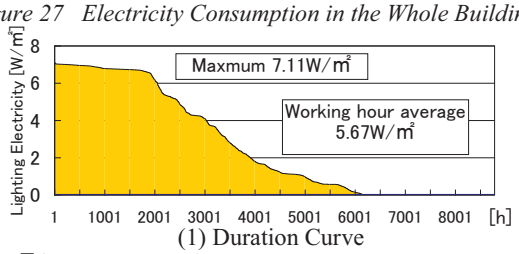
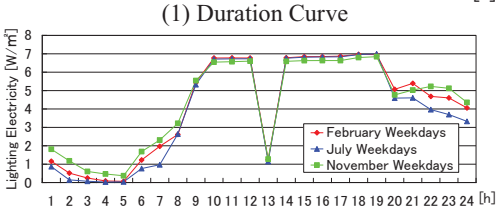


Figure 27 Electricity Consumption in the Whole Building.

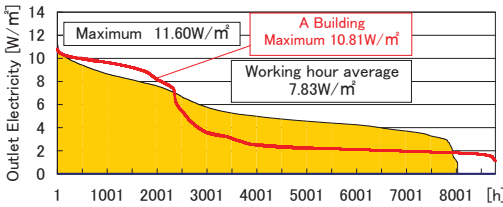


(1) Duration Curve

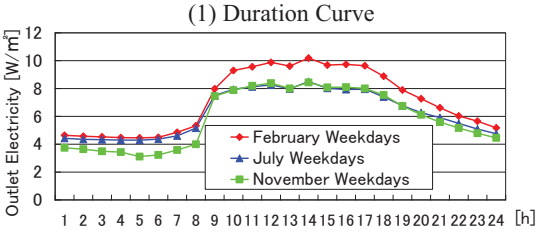


(2) Monthly-averaged Values

Figure 28 Electricity Consumption for Lighting in Exclusively-owned Office Space.

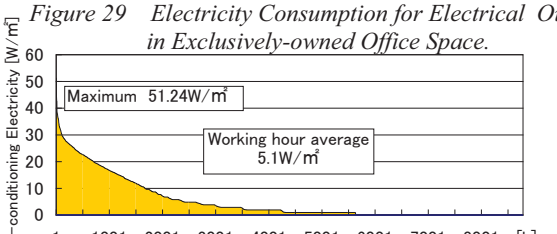


(1) Duration Curve

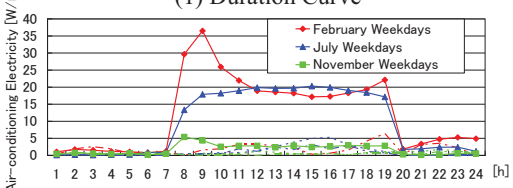


(2) Monthly-averaged Values

Figure 29 Electricity Consumption for Electrical Outlets in Exclusively-owned Office Space.



(1) Duration Curve



(2) Monthly-averaged Values

Figure 30 Electricity Consumption for Air-conditioning in Exclusively-owned Office Space.

WATER BY DESIGN: A SHIFTING PARADIGM IN URBAN BUILT ENVIRONMENT

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CPG Consultants, Singapore

ABSTRACT

Both local and overseas, CPG Consultants Pte Ltd (CPG) has been involved in Water Sensitive Urban Design (WSUD) from planning, design, implementation to post-implementation monitoring. This paper documents valuable lessons in urban planning. WSUD is an integrated approach to urban planning that requires the interaction of various disciplines, namely planning, urban design, architecture, landscape, civil and environmental design; to derive a creative solution that challenges the current planning and design of built environment.

In the paper, macro-level considerations are outlined through CPG's experience in the ABC Waters master plan. River master plans were developed and pilot projects identified. In a comprehensive manner, this paper shares the experience and calls for water to be designed as an integrated part of a sustainable built environment.

INTRODUCTION

In history, the emergence of civilisation is often dependent on the availability of water. Today, many examples of urban settlements in waterways still exist in Asia. As population increases and economic condition improves, cities move inland. Yet, despite advances in technology, cities continue to grapple with the issue of water. Although, we may never return to living in waterways, there is an urgent need to review on the relationship between people, space and water, to design and build sustainable developments that are sensitive to water.

WATER IN URBAN BUILT ENVIRONMENT

Ecologically sustainable urban built environment has evolved significantly all over the world. One of the important key aspects in ecologically sustainable urban built development is to preserve and conserve the water resources. Many communities have started incorporating WSUD practices into their water and storm water management plan. WSUD is gaining popularity in the world for its contribution to a holistic approach to urban water cycle management.

Singapore is one of the countries that have successfully incorporate the concept of water sensitive urban design to the urban built environment because of the challenging environment of a densely populated island. In order to achieve the sustainable urban built environment, Singapore has to preserve and conserve the water resources through the integrated water management approaches such as the reuse of reclaimed water, the establishment of protected areas in urban rainwater catchments and the use of estuaries as freshwater reservoirs. In addition, Singapore has developed a water catchment masterplan to impart the importance and value of keeping water catchments clean as more than two-thirds of Singapore will be water catchments in the long term (Luan, 2010). In line with the water catchment masterplan, Singapore has started building the urban reservoir by damming the major rivers in order to maximise the water storage.

Currently, Singapore uses two separate systems to collect rainwater and used water. Rainwater is collected through a comprehensive network of drains, canals, rivers and stormwater collection ponds before it is channelled to Singapore's 17 reservoirs for storage. This makes Singapore one of the few countries in the world to harvest urban stormwater on a large scale for its water supply. With all the major estuaries already dammed to create reservoirs, PUB aims to harness water from the remaining streams and rivulets near the shoreline using technology that can treat water of varying salinity. This will boost Singapore's water catchment area to 90% by 2060 (PUB, 2012).

Despite Singapore has prepared the blue masterplan, as a city-state that located in tropical region Singapore cannot completely exempted by the tropical region common problems of flooding. While flooding can be result of natural weather events such as heavy rainfall, prolonged rainfall, thunderstorm or high tide, many experts argue that flooding can also be the result of lack of proper urban infrastructure planning in the face of rapid building in urban areas. This can lead to inappropriate development of flood plains; poor channelled rainwater runoff, or badly designed flood defence system. Other factors that can contribute flooding in urban built environment are often a result of many human-related factors such as lack of maintenance of sewer networks, drainage networks, and watercourses.

When in fact at the macro level of infrastructure planning system this rainwater collection will be harvested, collected and channelled through the comprehensive network of drains, canals, and rivers before it is finally channelled to the urban reservoir. Preserving and conserving water resources such as to harvest the rainwater is a big challenge for Singapore due to the flooding issue that cannot be avoided. Hence the WSUD has been introduced in Singapore's practice of water and stormwater management plan

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through its blue masterplan and ABC Waters program. The detailed aspects of implementing and maintaining the water quantity and quality also become an important agenda in Singapore's stormwater management plan.

WATER BY DESIGN: CPG EXPERIENCE

As a key consideration in planning and designing an ecologically sustainable urban built environment that are sensitive to water should be taken from the macro level. CPG has participated in the making of one of water catchment masterplans of Singapore. The recommendation that CPG always suggest in every project is to set designated uses, and associated water quality objectives. There is a need to look back at the relationship between people, space and water. At the macro planning level, to be responsible to the ecology of urban built environment a complete picture of the existing conditions should be analysed in terms of climate, geographical aspect, water nature, landuse plan, historical and cultural value. CPG implemented five such projects, where aside from integrated technical considerations, government agencies' concerns had to be addressed. Important learning points on the micro-level issues of implementability and maintainability of public spaces and infrastructure are also crucial factors. These form the basis for new hydrology driven urban design.

PROJECT CASE

The project cases that CPG has developed and implemented explore opportunities for better integration of stormwater management and land use in three different types of urban development. The first type is the infill urban development adjacent to waterways. The second type is revitalisation of matured urban development flanking waterways. Finally third type is green field urban development driven by presence of waterways.

Urban Infill Development

Lorong Halus Wetland



Figure 1 Lorong Halus Wetland Location Map

Lorong Halus Wetland is located next to the Serangoon Reservoir, which is the 17th reservoir in Singapore. Lorong Halus is a former landfill site. It has been the site for non-organic landfill since 1960s but the activities has ceased with effect April 1999.

With the damming of Sungei Serangoon and its conversion into a reservoir, rainwater that falls on the landfill will now be drained into the reservoir. The Lorong Halus project has two very important milestones to fulfil namely, treatment of leachate from former Landfill, urban revitalisation of site to create valuable recreation spaces.



Figure 2 Leachate Treatment

In order not to compromise, the idea of the 9Ha wetland was mooted and eventually constructed as the test bed for the use of bio-remedial and phytoremediation techniques in Singapore.



Figure 3 Phytoremediation

A cut-off wall and pumping system was installed along the edge of the landfill to collect and channel leachate to the constructed wetland for treatment. Within the wetland, the leachate is passed through a route of aeration ponds, sedimentation ponds, reed beds and polishing ponds to achieve the desired water quality.

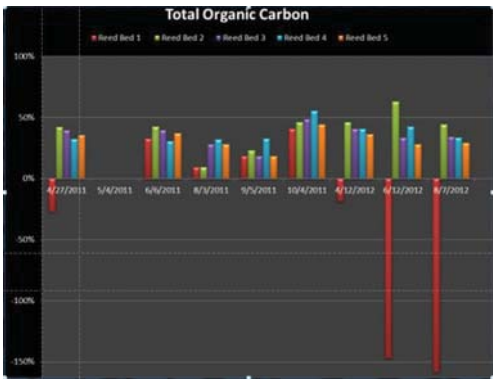


Figure 4 Removal Efficiency

Hydrologic assessment and extensive monitoring of water quality were conducted during the construction stage. In short, this project is the outcome of a number of research and development initiatives. Within the wetland, an interesting ecology strives. Besides cleaning the leachate, the plants in the reed beds support a habitat for migratory as well as local birds.



Figure 5 Footbridge from Lorog Halus to Punggol Promenade

With the construction of a footbridge, the Lorong Halus wetland is linked to the Punggol Promenade and Punggol New Town. Lorong Halus is now made very accessible to the surrounding residents. Not only has it retained its tranquil charms for bird watchers and nature lovers, it is now a public space for the heartlanders. The Lorong Halus Wetland is an environmental driven solution elevated to the realm of a public space. It not only maintains the connection to nature, but also opens an exciting window to the future of sustainable water sensitive design in Singapore.

Sengkang Floating Wetland



Figure 6 Sengkang Floating Wetland Location Map

The Sengkang Floating Wetland is located in the Punggol Reservoir. The reservoir was created by damming the Sungei Punggol. The planning objective at macro level was to stitch together parks and community spaces on both sides of Punggol Reservoir, namely, Sengkang Sports and Recreational Centre and Anchorvale Community Centre on the eastern bank and Sengkang Riverside Park on the western bank. In search of a solution which would embody seamlessly all principles of PUB's Active, Beautiful and Clean Waters Programme, the idea of an island was first mooted.



Figure 7 Sengkang Floating Wetland Illustrative Masterplan

The island, half the size of a football field, is connected to one bank by a fixed foot bridge and to the other by floating boardwalks. The fixed footbridge ensures that there is enough height clearance for water activities in the reservoir while the floating boardwalks allow people to get very close to water edge.

The floating island is formed from polymer panels, jointed together with aluminum plates. The matrix of these panels is made of a polymer material (Denier Polyester) where reed grows. In the micro level consideration whereas the implementability of this project is a crucial factor, the design aims to create semblance of nature albeit a highly engineered solution. The choice of the polymer medium allows a naturalistic profile to be adopted for the island. The wetlands that flourish on the floating island are widely recognized as eco-technology which purifies water through two mechanisms:

- The roots provide a substrate for microbial communities, which aid in the chemical transformation and uptake of nutrients present in the water; and
- The bio-film found on the root systems retains suspended solids which are in turn removed by grazing aquatic animals or alternatively by harvesting.

With the full establishment of the wetland plants, the island is now a picture of wilderness and tranquility. Because the island is created in the reservoir, hydraulics and hydrodynamics within the reservoir becomes important design considerations. These include:

- No significant reduction in reservoir storage with the floating nature of the island;

- Normal operational water level of the reservoir to enable accessibility for all users, including the handicap visitors;
- Flood level (100 year return period) of the reservoir.

Two anchorage systems are adopted, i.e. guide pile system and anchorage block system for the floating island. Both anchorage systems have been designed to allow the floating island moves in accordance with the changes in water level during normal operation and major flood events;

- Drag force on the floating island, due to wind and fast current during heavy rain events, considered in the design of the floating island and anchorage system;
- Wave impact from upstream fast current. Aluminum floating pontoon, designed as an access for maintenance workers to the floating island, is placed at the frontier part of the island to receive wave impact and therefore protect its downstream floating island from being affected during major storm events.

Above all, the most exciting outcome is the creation of a public space that promises new opportunities for recreation, reinforcing neighbourly ties, partaking in sports or simply, enjoying nature and being close to water.

Mature Estate Development

Sungei Sembawang Concept Plan Proposal

Sungei Sembawang is located in the northern region of Singapore. It is surrounded by Woodlands new town, Sembawang new town, Sembawang Shipyard and industrial area. Because of the presence of industries, the whole catchment is probably a High risk area in terms of Water Quality. While there is a network of canals in the area that drain into the waterway, the waterway is essential still subjected to tidal effects. Besides the usual engineered solution, PUB (Public Utilities Board) has successfully enhanced a stretch of Sungei Sembawang adjacent to the HDB (Housing and Development Board) housing by widening the canal and creating a permanent water body with lush planting along its' banks. Interesting biodiversity flourished in the vicinity.

What CPG like to achieve in Sungei Sembawang is an alternative urban planning holistic approach coupled with enhanced hydraulic concepts that will transform the canalized waterways. The vision is to re-establish the communities' connection with the water and all the associated pleasures that water brings. In short, seek a new leash of life for the area, made possible by River Revitalisation.

Both Woodlands and Sembawang housing estates were built following the principles of new town master plan. They are well serviced by schools, neighbourhood centres and neighbourhood parks. There is an opportunity for a new blue network that will certainly enhance the existing offerings. It will also improve the availability and quality of the public spaces in the industrial area, as well as connectivity to and within the industrial area. The blue network comprises of Water Concourse, Water Plazas, Water Streets, and Water Squares. A new concept of Green Valley is also added to enhance the blue network.



Figure 8 Sembawang Hydraulic Assessment and Masterplan

At micro level the interesting concept in this project is the idea of the Water Squares. In collaboration with De-Urbanisten from Netherland, the design proposal is to convert an open space adjacent to a school to Water Square. The Sports field in the school has an underground storm water storage tank.

The Water Square can be designed to fit Singapore's tropical rain conditions. There is opportunity to integrate the Water Square idea with the storm water tanks, many which are located in HDB estates and tend to sterilized land-use around them. Conceptually, the Water Square consists of two system interventions. The first intervention is a slightly sunken plaza where stormwater from adjacent roofs and public spaces is being collected and lead through the Water Square in artificial, shallow streams. These streams lead to a deep second part of the Water Square, the canyon. In the canyon the stormwater is collected and led through plantation terraces. From the terraces the water flows into an open basin at the bottom of the canyon. From this open basin the water is led into the existing covered storm water storage tank.



Figure 9 Watersquare Concept

The second intervention of the water square is related to the canyon. In the canyon one extra step is introduced between the existing covered canal and the covered storm water tank: a waterfall. With this 'spectacular' element, the covered canal overflows

into the open basin that leads back into the existing covered basin. The open basin at the bottom of the waterfall is not accessible, but visible and enjoyable. When heavy rain continues to occur for a longer period, the canyon can be flooded along with the water level of the covered basin. When this is expected to happen, the canyon will be closed to public. In line with the planning vision of connecting the changing of weather to the Water Square will celebrate both the Wet and Dry weather.

The concept to convert the reserve land north of Woodlands Ave 12 into the Green Valley is considered. The Green Valley proposes to take a bolder step forward to combine development of real estate and water storage. It is an integration of a green storm water landscape with future housing or mixed commercial land use. The Green Valley concept should be implemented simultaneous to the real estate development of the zoning plan. The impact of the Green Valley goes beyond the public area and is intertwined with real estate values. In the Green Valley urban development, stormwater treatment and the creation of a park environment are completely integrated. There are essential four elements in the Green Valley, namely, Green River, Retentions, Ponds as well as a System of Swales that connect all the WSUD features together and finally the canal.

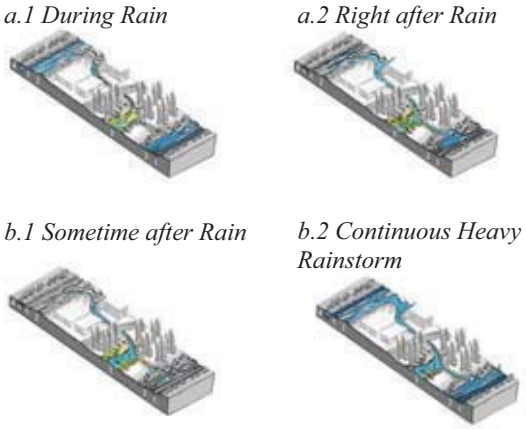


Figure 10 Green Stormwater Landscape Modelling

Here culture and nature closely coincide in an urban solution that evokes the time when Sembawang River was a natural river leading to the sea. The Green Valley allows stormwater to visibly flow from higher elevations into the lower constructed canal. In the time of heavy rainstorms occur, the green environment changes into a blue environment, all within safe boundaries. These dynamics in the appearance of the Green Valley will help people understand what effect a natural phenomenon can have. Lastly, it will be good if the whole notion of WSUD principles could be extended deeper into the heart of the older industrial estates, some of which may be due for urban renewal. A wide spectrum of mechanical and WSUD tools could be employed to achieve the water treatment objectives; from covering up the open storage areas, harvesting the water from the roof, to use of pervious material and bio-retention measures along canals and public roads and using available open space along waterways to create water plazas.

Greenfield Development

Hanoi VanGiang Ecopark

This is a township development 15 km off the heart of Hanoi and predominantly on the south bank of the Bach Hong Hai River (BHH River). Occupying some 500 Ha, the development comprises largely of waterfront housing, golf course housing, shop-houses and high rise mixed use development. Water is the single most important element in this master plan. Hence, at macro level the strategies are to achieve water quantity and water quality surfaced very early in planning and forms an integral part of the overall planning approach. Like many green field sites in these cities, the site is originally agricultural land and continues to be surrounded by plantations and farms.



Figure 11 Ecopark Masterplan

In the micro level consideration, an irrigation canal runs through the site, supplying water from the BHH River to agricultural land downstream. Water Balance is important not only to prevent flooding, but also to ensure there is a constant supply of water in the irrigation canal. Under normal condition, Gate D is closed to ensure that the source of irrigation for surrounding agricultural land is not compromised. In the event of storm, gates B and E are closed to prevent the influx of water from the river. The canal is used as an overflow for stormwater within the site and Gate D are opened to allow the stormwater to be discharged and pumped out at gate c. In addition, we have to design a cut off system along the perimeter of the site to take run-off from surroundings and discharge to the KTO canal.

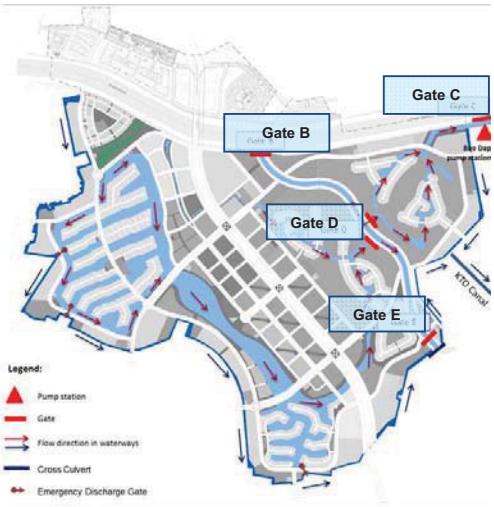


Figure 12 Flood Control Modelling

Water level of all the water bodies within EcoPark is designed in consistency with flood control system in the slide before. Three weirs have to be incorporated to meet the desired water levels. The platform level of all the development within EcoPark is then modelled to make sure that we meet the standard of 1 in 100 year flood, and yet not compromised future urban design of the water edge. It is interesting to note that the EcoPark master plan started as early as 2006. There was a very serious flood in Hanoi in 2008. After, the master plan was reviewed to make it more robust in terms of flood mitigation. All the water bodies within EcoPark are connected.



Figure 13 Water Balance

The source of the water is the Bach Hong Hai River. A flushing system is adopted to facilitate circulation of water. However, drawing water from the river is not a sustainable solution. The water bodies have to be supplemented by harvesting rainwater within the site. Upon our advice, the Client opted for a stormwater drainage system separated from sewer system, which we tend to take for granted here in Singapore. The drainage system is kept apart from the sewer system. Although higher capital investment, such a decision allows the drainage system to be designed to support the storm water collection and water conservation objectives. On the subject of water quality, the proposal begins by zoning to master plan into different risk areas, based on three criteria; extent of impervious layer, population density and traffic intensity.

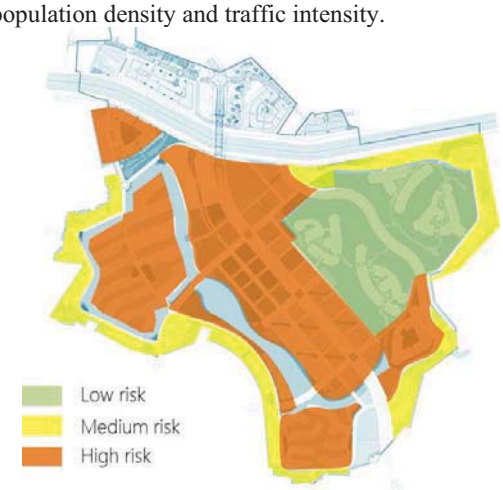


Figure 14 Water Quality

Provision is then made within the master plan to adopt different WSUD tools to deal with different risk areas, e.g., Rain gardens, retention ponds, constructed wetlands for high to medium risk areas and green buffer and planting strip for low risk areas. The different risk mitigation measures are then combined with the strategy to create a sustainable water body in the master plan. First and foremost, provision is made for a sizeable wetland next to the Bach Hung Hai River to treat the water intake from the river. As explained earlier, this intake will be supplemented by storm water collection within the site. Hence, there will be more treatment measures along the water loop to maintain the water quality along the way, not forgetting a flushing system to ensure water circulation.



Figure 15 WSUD Features

Constructed wetlands are shallow, extensively vegetated water bodies, designed with the intention to promote interaction between water, vegetation and hydraulic structures. Other than enhancing water quality, wetlands are often selected for the ecological values that they bring. Bio-retention features are used to enhance the water quality along the water loop. These bio-retention features are designed to be aesthetically pleasing and usually include an under drain, connection to storm drain system, complete with engineered soils, gravel drainage layer, sand filter layer, energy dissipaters. With the water quality and quantity issues addressed at planning level, the urban design can now come in to create the spatial characters for the public spaces.

Kallang Riverside Urban Design Guidelines

The site sits in the heart of historical modern Singapore. At the end of the Kallang River, it supported the rise of Singapore's status as a world-class port city through the industrial shipyards and was home to the Kallang Gasworks. Existing infrastructure, the waterfront and proximity to the CBD makes it prime land. Kallang Riverside will be the pilot project for Singapore to implement WSUD at precinct level, setting yet another new benchmark for country's stormwater management. In collaboration with ADA (Atelier Dreisetl), at macro planning level CPG aims to achieve a balanced approach to manage water in a responsible way that will promote healthier living in harmony with the environment.

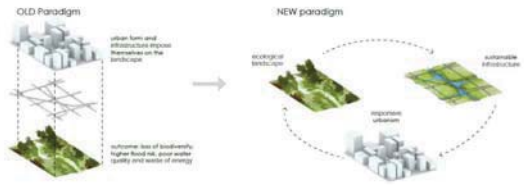


Figure 16 Self-Sufficient Neighbourhood

The objective of this pilot development of Kallang Riverside is to minimize its footprint with regards to urban runoff and stormwater pollution. To achieve this, the whole development is planned to achieve a runoff value that is equal to predevelopment conditions. Conventional developments usually exhibit high runoff coefficients where 70% to 100% of all water that falls on site ultimately becomes runoff. Because of the outdated "end of pipe solution" all the rainwater resource is conveyed outside the development and is discharged as fast as possible. This causes high stress on existing drains and public infrastructure. From an interdisciplinary standpoint, the main goal is to form a framework of WSUD tools that is low maintenance and resilient... This inherent flexibility of 'Designing with Water' yields clear environmental, social and economic benefits for this development.

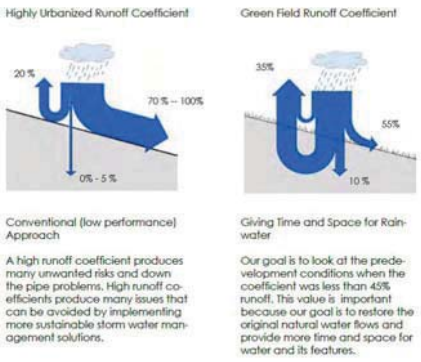


Figure 17 Runoff Coefficient

The main objective of rain water management in Kallang Riverside is to maximize the way that water resources are stored, cleansed, reused and released according to the pre development runoff target of 0.45. The proposal is to deploy a series of water management tools that together form a network that is resilient, efficient and capable of changing through time. Kallang Riverside precinct is a unique neighbourhood of residential developments that is in close proximity to a vibrant waterfront and a central green spine. It will be home to about 10,000 residents housed in high density residential towers.

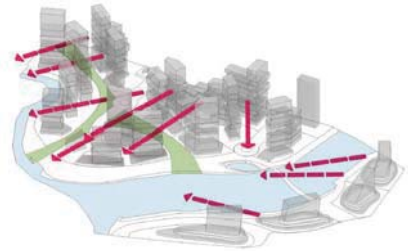


Figure 18 Visual Connections Porosity

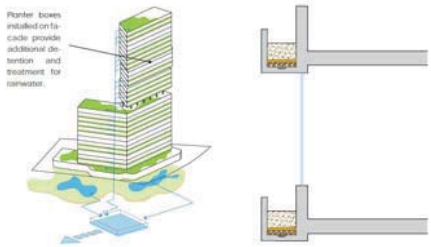
Apart from the waterfront and the central green spine, portions of the site also offer great views to the city, the riverside hotels and the future sports hub. The social goal of this requirement is to ensure that the residents feel part of the waterfront and the city beyond. Preserving visual connections from community decks, residential units and promenades towards the public parks and natural settings will be critical to contribute to Singapore's high density liveable city reputation. The development parcels in the precinct should respond to this objective by adapting creative design solutions. There will also be a mandatory requirement in the parcel guidelines, specific to each parcel, to provide a minimum spacing between towers to fulfil this performance objective. In terms of the sensitivity of the development to water, at the micro level strategies certain tools will be applied, namely, the Green Roof strategy, Façade Planters, Bioretention Basins, Vegetated swales and Cleansing biotope.

Green Roof Strategy



Green roofs in this development will serve to significantly reduce the amount of stormwater runoff by holding back as much as 75% of rainwater from ever reaching the roads and hard surfaces at the ground levels. All private developments will have to comply with 50% of green roof cover on their roofs (80% in school parcel). The layers of the green roof should be arranged to maximize retention, support plants, and perform adequate treatment. The green roof system should incorporate adequate drainage downpipes to underground detention cisterns. This system requires that the roof is receives a waterproofing membrane and that all layers area arranged to maximize treatment and retention. The system requires a modular installation process periodical maintenance check of drainage performance to eliminate clogging and confirm that filter layer is adequately meeting treatment standard.

Façade Planters Strategy



Planter box system designed to provide additional space and time for rainwater as it navigates down from roofs onto the ground level. The facade planters serve the additional purpose of accommodating rainwater, providing additional treatment and extending the amount of green provision in a private parcel. When rain falls on a roof, the façade planters can receive additional rainwater and cleanse it. As water percolates, filter media removes contaminants. Then afterwards the water can navigate downwards via a vertical downpipe. A downpipe connection should be installed to take water down to the ground where it can be discharged. Planter boxes require regular maintenance to ensure that infiltration capacity is maintained. Plants should also be maintained to ensure TP & TN uptake. The use of treatment elements does not have to be limited by the lack of space. Planter boxes can be implemented in a tiered or multi-level and sequential system to achieve water treatment performance. There is a lot of potential for Kallang Riverside to incorporate high-rise greenery into the living environment. These existing trends could be combined with rainwater management to harness intelligent and effective water harvesting capabilities.

Bioretention Basin and Underground Detention Tank Strategy

Bioretention basins are WSUD elements that offer a very complete rainwater management function. They serve to both provide space for rainwater (detention) as well as provide treatment performance. During rain events, water arrives to the basins and becomes stored, and up to 30 cm depth, the water is detained, avoiding discharge. This serves to shave off the peak discharge rate and makes land parcels perform in a more water sensitive way.

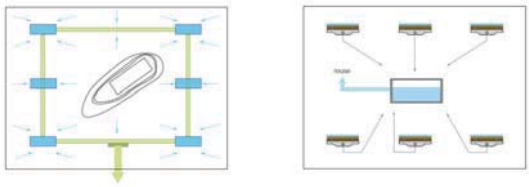


Figure 19 Surface Dainage-Bioretention-Infiltration-Detention Strategy

In short, Kallang precinct is a key player in advancing Singapore's vision to assist the government to mandate this approach in its subsequent sales of land parcels within the precinct, a cost benefit analysis was carried out. The analysis establishes the financial benefit of WSUD.

CONCLUDING REMARKS

Water by design in today's built environment requires truly multi-disciplinary expertise. It begins with a bold design vision at a macro level, underpinned by strong engineering fundamentals at the micro level. On top of that, it needs to be supported by extensive data collection prior, during and post implementation, as maintainability after completion is central to the success of the design. However, a sustainable approach towards Water by Design is the way forward for cities, particularly the high design development in Asia. City planners and design professionals must acquire the knowledge to undertake such challenges.

ACKNOWLEDGMENT

This paper is a summary of various documents and reports from the projects.

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OPTIMISATION OF OUTDOOR AIR COOLING SYSTEM FOR MODULAR DATA CENTRES

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ABSTRACT

This paper presents the initial results of optimising the use of outside air for cooling modularized data centres (MDCs) under tropical climates. MDCs with outside air-cooling have been in use in temperate climates. The concept was test-bedded in Singapore for the first time at Nanyang Technological University (NTU). The initial operation data showed that there is a potential of 73% of time, the data centre can be operated using only outside air or mixture of outside air with warm return air. Here, we analyse the cooling system performance of the MDC test-bed with the aid of energy models and standard weather files to evaluate the possibility of cooling mode control algorithm in the air-handling unit (AHU). The results show that, enthalpy based cooling mode control has the potential of maintaining consistent high-energy efficiency of outside air cooled MDC at low IT loads.

Keywords: Modular Data Centres (MDCs), outside air cooling, energy efficiency, TRNSYS

INTRODUCTION

Data centres, that house and maintain the back-end information and communication technology (ICT) systems, represent a large chunk of energy footprint of many buildings in our cities. Modern ICT equipment such as high performance servers used in data centres requires much higher heat release per unit area making development of new cooling technologies a necessity for future applications. In the high temperature and high humid tropical climate in Singapore, provision of adequate and efficient cooling for data centres is challenging and, according to National Environment Agency (NEA), currently represents about 50% of their energy cost. Therefore, it is important to look into energy efficient data centre cooling technologies for tropical climates in order to achieve future sustainability of our modern cities.

Outside air cooling of data centres have been used in countries where temperate climate conditions prevail. Recent studies have been published on the potential of using economizer cycles for building ventilation and cooling [1, 2, 3], data centre cooling [4, 5, 6, 7], and energy analysis of such cycles in building ventilation [8]. It has also been shown that the use of economizer cycles can save on energy bills and help to maintain a low total cost of ownership [9, 10]. Lee and Chen [11] reported that data centres in Singapore have a marginal potential of energy savings using outside air for cooling under current ASHRAE recommendations.



Figure 1 Modular data centre test bed at NTU campus

The remainder of the paper is organised as follows: First, we introduce the modular data centre and its cooling system. Next, we present analysis of cooling modes currently employed and discuss the possibilities of enhancing the cooling performance under both high and low ICT loads.

MODULAR DATA CENTRE

Scalable modular design is one of the key practices to maintain high energy efficiency throughout the lifetime of data centres [12]. Modularized data centres are one of such technology that can be used to expand the data centre resources of an organization as it grows. It has a number of advantages, such as quick deployment, high density, and an integrated, single supplier IT and infrastructure solution. They are also used to cater for regular changing demands as in the case of cloud computing business scenarios.

The modular data centre test bed shown in *Figure 1* was built in NTU campus as collaboration between NTU and Toshiba Asia Pacific Pte Ltd under Green Data Centre Innovation Challenge by Infocomm Development Authority (IDA) of Singapore. It is equipped with an outside air cooling system supported by mechanical cooling system described

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below to fulfil its cooling demand. The objective of this project was to demonstrate the viability of this outside air cooling technology in tropical climate and analyse its performance.

ICT Module

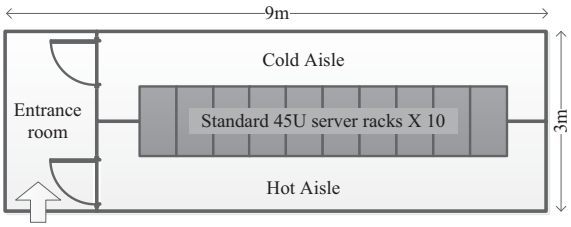


Figure 2 Schematic floor plan of modular data centre

The modular data centre test bed consists of ICT module and air conditioner module as shown in *Figure 1*. The footprint of the data centre is 9m by 3m, which is similar to the size of a standard 20 feet container. As illustrated in *Figure 2*, the ICT module houses 10 standard 45U racks. The hot aisle is physically separated from the cold aisle with a wall to eliminate airflow inefficiencies inside. *Table 1* gives a summary of ICT module specifications

Table 1 Specifications of ICT module

Modular data centre footprint	9m x 3m
Number of server racks	10
Maximum ICT load per rack	9kW
Maximum ICT load of data centre	90kW
Supply air temperature at cold aisle	28~32°C
Return air temperature at hot aisle	37~39°C

Air Conditioner Module

The air conditioner module is placed upon the ICT module as indicated in *Figure 1*. This module is designed to primarily use outside air to meet the cooling demand from ICT module. Direct expansion cooling coils are installed to supplement the cooling demand where outside air conditions are unfavourable or to meet the entire cooling load when closed loop operation required. The schematic diagram in *Figure 3* shows the concept of using

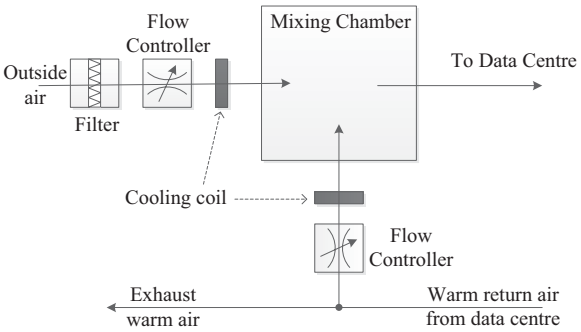


Figure 3 Functional schematic of air conditioner unit

outside air for cooling. To attain desired conditions, outside air is sometimes mixed with warm return air, dehumidified, and mechanically cooled as explained below.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is the primary organization that sets standards for data centre operation environments. In 2011, ASHRAE updated its published guidelines for temperature and humidity for data centre environments [13]. The envelope indicated by ① in *Figure 4* requires the strictest temperature and humidity control. Most mission critical data centres follow this guideline with temperatures at lower end of the envelope to allow lead-time for any cooling system failure as well as inefficient airflows if any.

Generally, ① envelope is sufficient for providing outside air for data centre cooling in temperate climate conditions. In the tropical climate in Singapore however, the conditions tend to hover in the area indicated by the dotted circle in *Figure 4*. In order to realize outside air cooling under tropical climate, air conditioner module of the modular data centre test bed has an extended envelope as indicated by ② in *Figure 4*. This results in increasing the desired dew point (DP) upper limit from 17°C to 24°C in the desired air condition with no changes to temperature or relative humidity (RH) conditions.

Table 2 shows the air handling unit (AHU) operation

Table 2 Operation modes of the air handler of air conditioner module

AHU OPERATION MODE	DESCRIPTION	TEMPERATURE (T), RELATIVE HUMIDITY (RH), AND DEW PPOINT (DP) CONDITIONS		
		T	RH	DP
M1	Cooling with outside air only	< 32°C	< 80%	< 24°C
M2	Cooling with outside air and mixing hot return air	< 32°C	> 80%	< 24°C
M3	Cooling outside air with compressor	> 32°C	-	-
M4	Cooling with compressor and mixing hot return air	< 32°C	-	> 24°C
M5	Cooling return air with compressor	Recirculation mode for control		

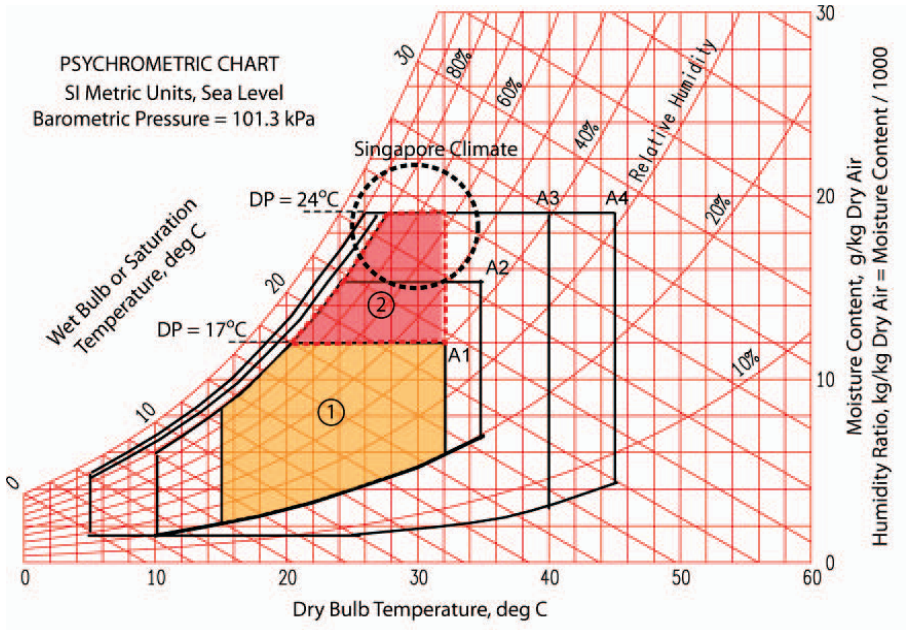


Figure 4 ASHRAE thermal guidelines compared with the conditions maintained within the modular data centre

modes of air conditioner module. Depending on the condition of the outside air, one of 5 modes is selected by the AHU controller to deliver the desired air condition within the ICT module. Here, cooling modes M1 and M2 are entirely rely upon outside air while cooling modes M3 and M4 are supplemented by mechanical cooling. Cooling mode 5 is not used under normal operation conditions and reserved for emergencies and controlled experiments. Note that, conditions maintained within the ICT module so that DP does not decrease below 24°C to avoid possible condensation within ICT equipment and hardware damages.

ANALYSIS OF COOLING MODES

Quantifying Energy Efficiency

With outside air cooling, substantial energy savings can be gained since the mechanical cooling system is not used. The most common measure to quantify the energy efficiency of a data centre is Power Usage Effectiveness (PUE) [14] metric that is defined as the ratio of the total energy drawn by a data centre to the energy used by the ICT equipment in the facility:

$$PUE = \frac{Total\ data\ centre\ energy}{Total\ ICT\ energy}. \qquad (1)$$

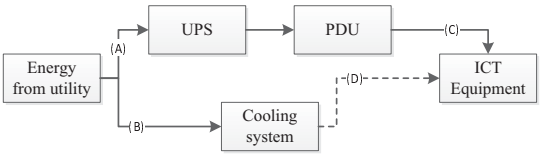


Figure 5 Definition of PUE

As illustrated in *Figure 5*, efficiency of a data centre could be improved by reducing the energy used in the cooling and power supply architecture.

In our case, the modular data centre does not have a uninterruptible power supply (UPS) system in place. This is the common practice with modular data centres since they are designed to rely on a reliable power supply system from a base station. Therefore, in order to differentiate the energy efficiency figures from data centres with UPS systems within their perimeter of calculation, we use the term partial PUE (pPUE) [14] to refer our energy efficiency calculations.

Figure 6 shows the measured energy consumption data of the modular data centre for the two months, December 2012 and January 2013. It has been operated around 60% ICT load (≈ 60kW) and the daily averaged pPUE is within the range of [1.2,

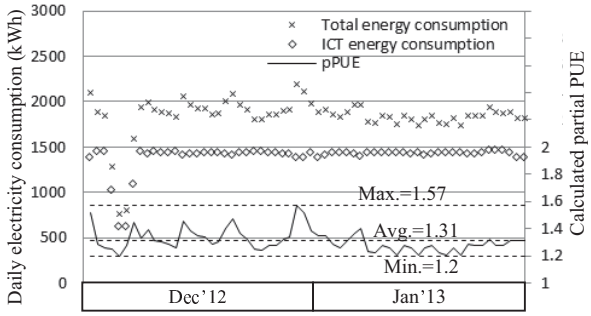


Figure 6 Daily measured energy consumption and calculated daily mean pPUE of modular data centre for Dec'12 and Jan'13

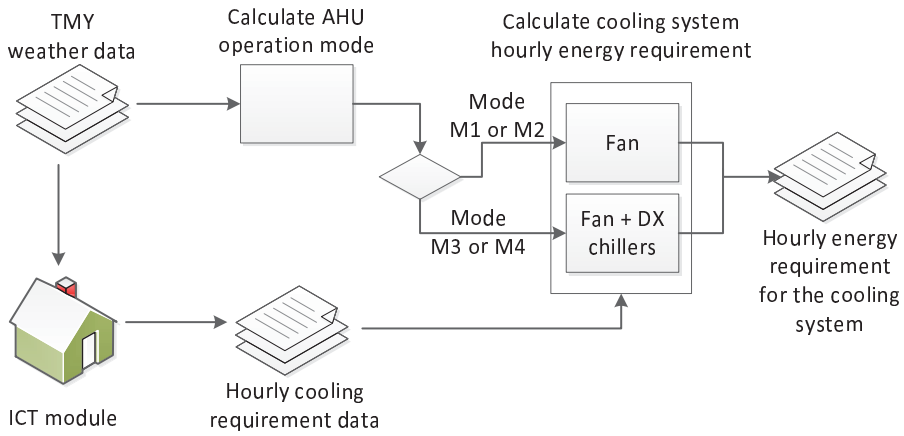


Figure 7 Schematic of modular data centre energy simulation with TRNSYS

1.57] with overall average of 1.31. The average PUE for a Singapore data centre is 2.07 according to National Environment Agency in Singapore [15]. With the pPUE values mentioned, the modular data centre can be expected to perform PUE values well below the Singapore average.

Energy Model of Modular Data Centre

Due to high operation temperatures, the cooling system primarily rely upon outside air with supplementary conditioning using hot return air and cooling coils. With high ICT loads close to 90kW (close to 100% ICT utilization), this may be very effective since the temperature of return air from the ICT module is close to 40^{o}C which is well above the outside air conditions in Singapore, making it effective to reject it to the environment and draw outside air for cooling. However, when the data centre is not running at its full capacity, this situation may not necessarily be true.

To analyse the effectiveness of outside air based cooling system, we developed an energy model of the modular data centre that enable us to simulate and predict the energy efficiency levels at different ICT loads.

The modular data centre energy model was implemented in TRNSYS [16], a simulation program primarily used in the fields of renewable energy engineering and building simulation. *Figure* 7 shows a schematic diagram on how the energy requirements are calculated using TRNSYS. The ICT module was modelled in TRNBuild, the tool associated with TRNSYS to model building energy demand, incorporating passive heat gains from ambient and internal ICT loads. Typical meteorological year (TMY) hourly weather data for Singapore was used in this case.

Hourly AHU operation mode of the air conditioner module can be calculated using temperature, humidity and dew point data in TMY weather data. Energy requirement for the cooling system changes depending on the AHU operation mode. For modes M1 and M2 only energy requirement is the fan and no mechanical cooling is involved. Whereas modes M3 and M4 involve mechanical cooling and dehumidification, hence energy requirement for DX chillers should also be considered in addition to the fan.

The simulator can be used to predict the air conditioner module energy requirement under different ICT loads, thereby calculate the pPUE. In this study, we investigated three ICT load set points, namely, 30kW, 60kW, and 90kW and calculated hourly spot pPUE values. *Figure 8* shows a plot of calculated pPUE values along with the AHU operation mode for the months December and January.

Energy Efficiency Analysis of Cooling Modes

From *Figure 8*, obviously M1 and M2 are the most efficient AHU modes with no mechanical cooling involved. However, it is evident that when mechanical cooling required as in the case of mode M4, pPUE increase drastically, especially so with low ICT loads. The range of pPUE variation for ICT load of 60kW is similar to that of *Figure 6*. This resemblance serves to be the validation of the simulation to perform further analysis. We also used TMY weather data to calculate the expected availability of each AHU mode in a typical year. *Table 3* summarizes this along with expected pPUE values for each mode at each ICT load.

Mode M3 gives the worst pPUE while M4 is not far behind. It is also important to note that the mode M4 can be expected 38.6% of the time of a typical year. If the modular data centre is operated with low ICT loads it will result in worse than expected energy efficiency performance.

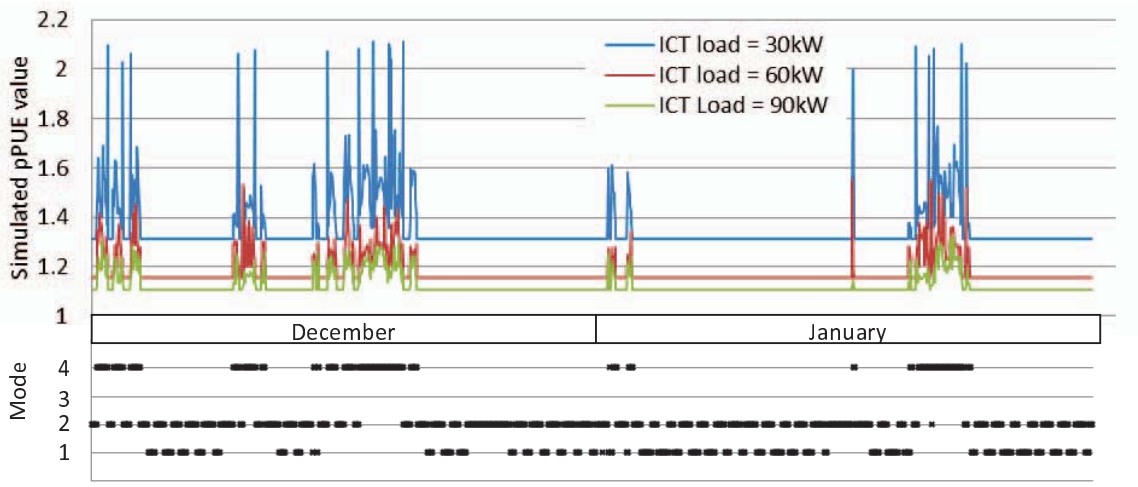


Figure 8 Simulated spot pPUE based on hourly standard Singapore weather data for the months, December and January

Table 3 Expected availability of each cooling mode in a typical year and expected averaged pPUE

AHU MODE	AVERAGE AVAILABILITY	PARTIAL PUE		
		ICT LOAD = 30kW	ICT LOAD = 60kW	ICT LOAD = 90kW
M1	19.7%	1.3	1.2	1.1
M2	40.5%	1.3	1.2	1.1
M3	1.2%	1.7	1.45	1.3
M4	38.6%	1.53	1.3	1.2
Annual averaged partial PUE		1.3935	1.2416	1.141

The reason for getting higher pPUE values at low ICT loads is twofold. Firstly, when the demand for cooling decreases with low ICT loads, chillers tend to operate at their low efficiency range. When chillers are required under this condition due to unfavourable outside air condition, higher proportion of energy is required for cooling system making pPUE value to hike. Secondly, at low ICT loads, recirculation of hot return air may be energy efficient rather than having outside air cooled and dehumidified with cooling coils.

In contrast to data centres in permanent establishments such as buildings and warehouses, modular data centres often used to supplement short-term ICT load increases and add-as-you-grow strategies. Therefore, it is important for modular data centres to be energy efficient in the whole spectrum of ICT loads.

Enthalpy Based Cooling Mode Improvement

To improve the energy efficiency of modular data centre at low ICT loads, there can be several measures taken as follows:

1. Use cooling coils along with the mechanical cooling system with wide-band high coefficient of performance (COP)
2. Reduce the resistance in air delivery ducts

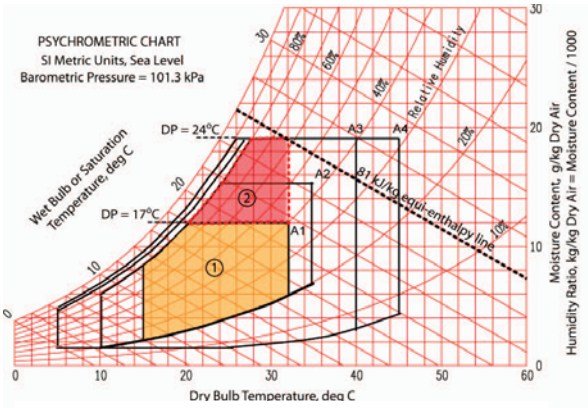


Figure 9 Enthalpy based cooling mode selection and modification

3. Improve cooling modes and selection algorithm to look into hot return air condition

In this paper, we investigate the third measure with simulated performance analysis.

As shown in the pshychrometric chart in *Figure 9*, the allowable supply air condition for the ICT module is depicted by the area covering regions ① and ②. Thus, the highest allowable enthalpy for the supply air becomes 81kJ/kg. We can use the 81kJ/kg

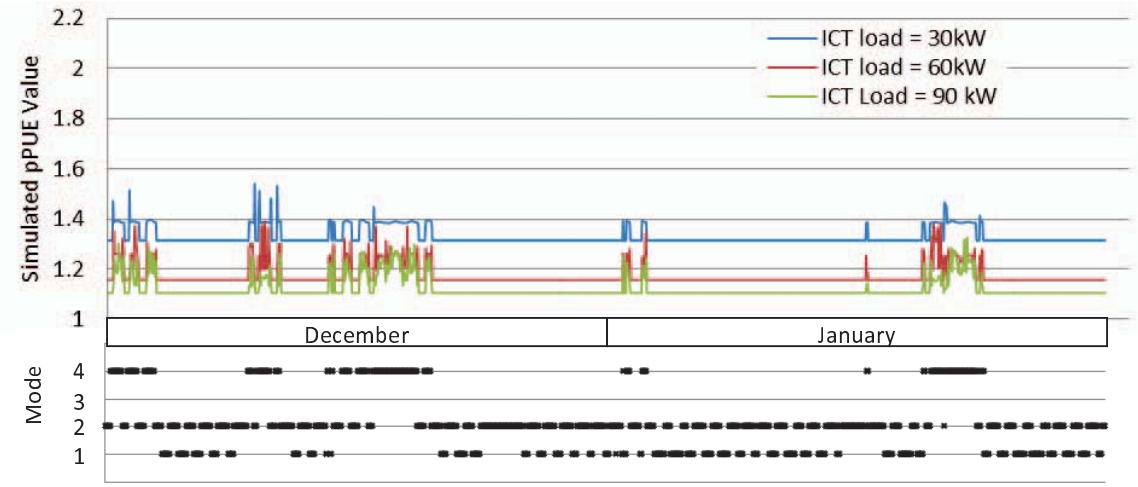


Figure 10 Simulated spot pPUE with modified cooling modes M3 and M4, based on hourly standard Singapore weather data for the months, December and January

Table 5 Enthalpy based improvement of cooling modes M3 and M4

OUTSIDE AIR ENTHLPY	RETURN AIR ENTHALPY	AIR SELECTION
< 81kJ/kg	< 81kJ/kg	Return air
< 81kJ/kg	> 81kJ/kg	Outside air
> 81kJ/kg	< 81kJ/kg	Return air
> 81kJ/kg	> 81kJ/kg	Use air with less enthalpy

equi-enthalpy line as shown in *Figure 9* as the guide to improve the energy efficiency of cooling modes M3 and M4. We can still use the logic in *Table 2* to determine the AHU operation mode. If mode M3 or M4 is selected, then we can look into *Table 4* to further select on whether to use outside air or hot return air based on their enthalpy level.

The advantage of using hot return air where possible is that it is filtered and dehumidified in accordance with the ASHRAE standards. Therefore, sensible cooling of hot return air may be energy efficient than de-humidifying and cooling outside air. Moreover, thorough filtering is not required in contrast to the case with outside air.

We simulated the energy efficiency of modular data centre with above modifications to AHU operation modes M3 and M4. *Figure 10* shows the simulated pPUE values for 30kW, 60kW, and 90kW ICT loading for the months December and January of a typical meteorological year. When compared with the simulation results of the existing system in *Figure 8*, pPUE values for mode M4 are not high as before. Specifically, with low ICT loads, the hikes in the pPUE values are similar to that of high ICT loads.

Table 4 Average pPUE for simulated modular data centre energy consumption for months December and January

ICT LOAD	AVG. pPUE (USUAL MODES)	AVG. pPUE (REVISED MODES M3, M4)
30 kW	1.53	1.39
60 kW	1.28	1.25
90 kW	1.2	1.2

One can also observe that the range of pPUE for all ICT loadings is now within the range of measured pPUE data in *Figure 6*. This is significant because it indicates the possibility of operating the modular data centre at high energy efficiency in all ICT loading scenarios.

Table 5 shows the expected pPUE for the two months simulated before and after mode M3 and M4 modified to look into enthalpy of outside air and hot return air. Even at averaged figures, the improvement is significant for low ICT loads while for high ICT loads there is no significant improvement. This is understood since the high ICT loads result in hot return air with enthalpy is more than 81kJ/kg making it energy efficient to cool outside air after discarding return air.

CONCLUSION

In this study, we analysed the outside air cooling system of modular data centre located at NTU. An energy simulator of modular data centre was implemented using TRNSYS and the performance was validated with 60% ICT loading results of measured operation data. We then simulated energy performance of the proposed enthalpy based cooling mode improvement and compared the pPUE figures

with that of simulated existing AHU operation modes. Our results indicate that the proposed enthalpy based improvement to select between outside air and hot return air is effective to maintain the high energy efficiency of the modular data centre at all ICT loads.

As for further research, we are currently working on studying the energy efficiency implications of lowering the current cold aisle temperature set point. This may reduce the burden on server fans as well as enable us to maintain supply air condition close to the ASHRAE recommended range.

ACKNOWLEDGEMENT

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SOCIAL AND ENVIRONMENTAL ASPECTS SIGNIFICANCE ON THE REBUILDING AFTER NATURAL DISASTER IN INDONESIA CASE STUDY: YOGYAKARTA EARTHQUAKE 2006

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ABSTRACT

The term of disaster is a critical issue not only because it affects to people life but also its impact to the environment. After Yogyakarta Earthquake 2006 in Indonesia, many new post-reconstructed housing was built by community participatory or donor driven project. Most severely damaged houses have been certainly reconstructed. Based on the vulnerability terms, Yogyakarta rebuilding project will be studied as an example. The discussion begins with understanding the correlation between disaster and the geographical location. It is conceivable if the disaster hits different parts of location and brings different faults. This fact allows us to compare why some areas are more vulnerable than others. This can lead to the characterization of different degree of vulnerability in sheltering options that can be differentiated into emergency sheltering, temporary sheltering, temporary housing and permanent housing. The reconstruction is a consequence of the disaster risk management, for supporting communities to re-establish their normal life and gradually reducing the degree of vulnerability. To evaluate a successfully project some key concerns are identified. It is mainly ranging from duration of a project to the selection of building materials in order to create comfort units. The unit cost implies not too be expensive and gives more challenges to connect with existing facilities. Furthermore it gives possibility to integrate unit design and settlement layout in order to establish a cost effective project. Reusing of materials coupled in a new design settlement is possible in the a small scale project and the community has accepted. On the other hand, the top-down scheme is necessary when the shelter needs to be provided quickly, while enabling residents to help themselves. Identifying what could be self-managed by the residents is needed to ensure a best-suited settlement.

INTRODUCTION

In the early reconstruction period following a natural disaster hit many houses, infrastructures, and facilities are rebuilt to ensure people living in a properly condition after a horrifying experience they have already faced. As soon as the emergency actions are done; such as: delivering food items, providing emergency tents or distributing toolkits for assembling emergency shelter, there is a critical time that sooner or later people need the past life back. Their daily activities in the emergency tents and or the transitional settlements are no longer sufficiently for them after some duration time. Usually after they have to go back to work and partially of them (children, women and patients/victims) have recovered from pain and fear; people need the normally life back by rearranging the house and the community. Some problems will be occurred related with land and property when the last disaster had been completely sweept away the land and the property. Most often by floods, volcano eruptions, earthquakes, or tsunamis, people are possibly losing the land for living and so do the farmland (UN Habitat, 2010: 4).

In the situation after disaster, community is in the middle of an uncertainty condition that makes them susceptible to the hazard effects. This condition is commonly known as vulnerability (UNISDR, 2009: 30). The term vulnerability values to identify what kind of shelter options are required to provide adequately settlements for the people. According to Lizarralde et al. (2010: p.5), post-disaster reconstruction aims to improve the pre-disaster conditions with the long-term achievement as an extensive concern in development. It is highlighted that the barrier for accessing the resources is the main problem in disaster situation. Therefore, it is understandable that the reconstruction phase is a consequence of improvement the resiliency; as the opposite of vulnerability. Through reducing the weakness factors the resilience state will be built. A reconstruction is a consequence of building the resiliency. However, the concept of reconstruction is still involved whether the reconstruction phase aims to build back to the level condition before disaster math or it also purposes to reconstruct the completely systems towards the future development.

Researchers suggest some criteria or key concerns to evaluate how good the reconstruction project is. It usually focuses on the period of time, adapting socio-cultural aspects to ensure the project suitable to the local community and planning for the future development. Bolton (1996: 166) implied that goals of the "good" housing reconstruction and recovery should meet the criteria, such as:

– be quickly available to survivors;

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- be socially habitable, that is, be consistent in type and location with their social and cultural identity, and permit them to maintain prior social interaction patterns;
- be sustainable to them, in terms of costs to live in it and maintain in a habitable condition;
- be safer in future earthquakes

On the other hand, Johnson (2010: 87) indicated that key concerns for planning temporary housing in the post-disaster period after her study in Turkey's 1999 earthquake must respond to:

- time of delivery;
- the approach to providing housing or enabling families to build their own housing;
- the cost and design of temporary housing unit;
- the location;
- access to services and maintaining social networks

Johnson formulated a distinction between the phases of time which the temporary housing planning will operate immediate after disaster period or in the long-term phase. Both criteria clearly mentioned the speed of the project should meet the community expectation. The situation of uncertainty is not comfortable and this is the reason why the post-disaster settlement requires a safe condition for the occupant. As stated by Bolton (1996: 177) that post-reconstruction and routine development housing as a long-term goals of disaster management to prepare the readiness of the community can be integrated.

NATURAL DISASTER, GEOGRAPHICAL LOCATION AND VULNERABLE CONDITIONS

The Centre for Research on the Epidemiology of Disasters (CRED) defines a disaster as "a situation or event, which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" (Guha-Sapir, Vos. & Below, 2012). CRED registered a disaster if pursuing one of the following criteria: 10 or more people kill; 100 or more affected people; declaration of a state of emergency; or a call for international assistance. The affected people indicate they who are evacuated, injured, displaced/homeless, or required immediate relief. Homeless identifies people who required immediate assistance for shelter.

Additionally, the geographical location has an important influence on how disaster affects people (Davis, 1978: p.11). It is conceivable when disaster hits different parts of location, it will bring also different faults. In unpopulated location an earthquake disaster strikes causes no significant faults and it is probably included as a natural phenomenon. Nevertheless, it results on landscape damage, such as; landslide, or fracture on the earth's surface but it can trigger to more dangerously disaster (McDonald, 2003: p.2-3). If the same event happens in densely populated areas it brings death toll and damages in livelihoods, as well as ruining of infrastructures or ecological damage. However, the phenomena of natural disaster are valuable to study with the purpose of improving man's ability to persist harsh condition. The researchers study the events to advance knowledge and technology to cope similar events in the next future.

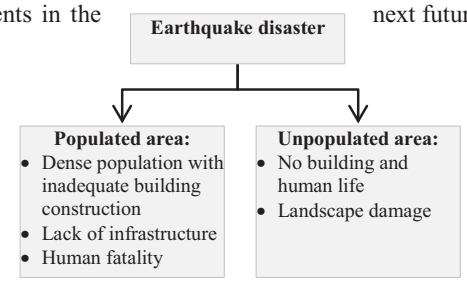


Figure 1 Earthquake event generates the degree of vulnerability of people and environment in densely populated and unpopulated areas

(Source: Davis, 1978)

Figure 1 gives an illustration of a hazard condition; an earthquake disaster increases the risk settings to the landscape, infrastructure and settlements. The increase of hazard level and the exposures will lead population more vulnerable. In unpopulated area with no human life and buildings, the event does not cause any casualties for people and building damages; but in populated area with poorly constructed building and lacking of infrastructure support system, it can cause fatality, destruction and devastation on built environment and becomes widespread. People on that area are more vulnerable to disaster. Today the situation of unpopulated area which running into landscape damage potentially triggers other disasters and has a high risk getting poorer. The environment degradation from economically point of view is a great loss and can give significantly impact in society. Furthermore, extensive landscape damage through seismicity activities creates environmental damage. This can lead losing of many species in the ecosystem and give contributions in the climate change. Even worse, earthquakes can be followed by landslides and destruction of roads and public services as well as initiate industrial or nuclear accidents that can pollute the water pipes and lands in countries far away (McDonald, 2003: p.6-7)

PROBLEMS ASSOCIATED WITH VULNERABILITY IN SETTLEMENT

The Yogyakarta earthquake in 2006 had been registered 63,807 affected people, which were 38,568 people injured and 5,778 brought fatality. Furthermore, GEMECD (Global Earthquake Model Earthquake Consequences Database) registered that the total number of damaged dwellings was 767,067 sources from National Coordinating Agency Bakornas report (Badan Koordinasi Nasional Indonesia). The number is bigger than the total dwellings damage from the earthquake and tsunami Aceh and Nias in 2004, which is approximately 365,000 dwellings destroyed and 320,000 dwellings became damage as a whole in this event. The cases deliver necessary information that factors as: the density of population, the location of the magnitude and the quality of the buildings affects to the destruction and the number of casualties incurred. Distinct with the Aceh case (Indian Ocean earthquake) epicentre locates in the depth ocean 30 kilometres beneath the seabed; the location of epicentre of Yogyakarta earthquake is on land 10 km below the seabed, with a magnitude of 6.2 RS (USGS). The unsafe situation in earthquake effects people in accessing the resources. According to GFDRR in Earthquake Reconstruction (2011), implies that in such situation, victims cannot access to a certain areas/logistics/infrastructures and immediate aid cannot reach the victims' location.

Table 1
The number of victims from two earthquake events in Indonesia (Source: GEMECD)

	ACEH EARTHQUAKE AND TSUNAMI 2004	YOGYAKARTA EARTHQUAKE 2006
People injured	100000	38568
Seriously injured	15000	19401
People missing	50907	0
Killed	177780	5778

Besides amount number of human death toll, the last earthquake 2006 in Yogyakarta also caused in destroying building includes of number of dwellings as part of the result. Figure 2 shows evidence from a disaster event that explains how an earthquake disaster triggers to the situation of increasing settlement demand in a short time. The total number of dwelling damaged indicates 57% houses abruptly become ruins by the ground shaking. The situation leads people to homelessness and the vulnerability increases due to the crisis time for accessing adequate shelter.

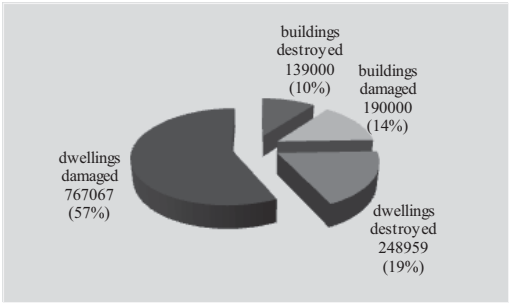


Figure 2 Total building damage in Yogyakarta Earthquake 2006
(Source: www.gemecd.org; Bakornas)

The number ogf buildings and dwellings destroyed which is shown in Fig 2 indicates the situation of homelessness. The number of building destroyed and the number of homeless people can be multiplied or more depends on the population density in an area. Furthermore in case of an earthquake disaster the magnitude earthquake has significantly meaning into the number of building destruction (UP Seis, 2013 and McDonald, 2003). In order to achieve the resiliency on sheltering options in the early post-disaster phase are strongly influenced by exposures. The human vulnerability will be increased in the crisis depends on the external exposures, such as: quality of the buildings, local standard, building site and land use management, social system includes disaster mitigation, social capital and economic support, education, indigenous culture, policies and humanitarian aid (Lizzaralde, et.al., 2010) .

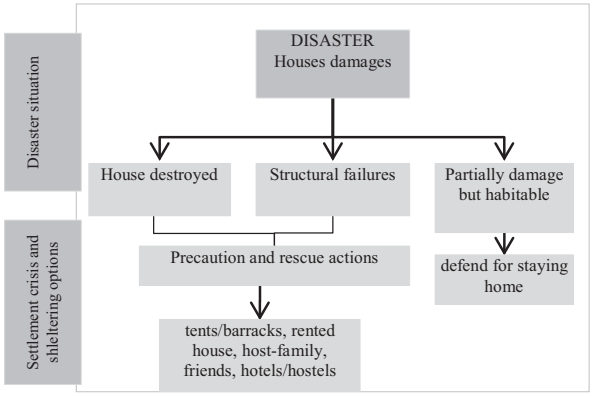


Figure 3 Sheltering options after disaster

(Fig 3) signifies that the damaged houses decline as long as the exposures have been handled, such as: improving the building quality guided by the building standard. Building on a poor location/slope site increases the number of homeless could be possibly clear from settlement. Meanwhile, the human vulnerability in accessing adequate shelter after a

disaster depends on the socio-economic factors and indigenous culture. These exposures will give influence on how long a person or a family should live in the temporary shelter or in evacuation place (tents, barracks, host families, etc). Different situation is shown by a certain group family who can stay at home as long as the house is still habitable and just partially damage with the provisions no further disasters and no other threatening hazards. Further the duration of living in temporary shelter depends on the hazard situation can be overcome by reaching resources with owned capacity. Thereby the short-term recovery planning after disaster aims to upgrade the resiliency of community through reduction the deficits.

OVERVIEW OF CASE STUDY IN NGIBIKAN-VILLAGE, BANTUL, INDONESIA

This paper is part of a doctoral research in post-reconstructed disaster housing in seismic area, which is taken at the Technical University of Braunschweig in Germany. The collected data was observed and documented two times in different periode in the duration of field research in Indonesia in the year 2011 and 2012. The research was assisted by architecture students from Duta Wacana Christian University (DWCU). The Ngibikan village is one kampung/village in Jetis subdistrict that received a donation from local newspaper's readers. Interview with the kampung-leader was done and recorded. A part of the observation, an interview with the architect (Mr. Eko Prawoto) who assisted in core-house design also recorded in order to give other point of view from expert side. The details descriptions of the case study are shown in Table 2. Reviews of the field research were then defined in the following discussions:

Table 2
Details Descriptions of Case Study

Case study	Post reconstructed housing Ngibikan Village Community
Disaster type	Natural disaster, Yogyakarta earthquake 2006
Ethnic group	100% javanese
Status	100% owner of house and land
Rebuilding plan	Post-disaster reconstructed permanent house by self-design and community participatory building method
Area/location	Rural area of Yogyakarta Special Province in Center-Java A village with 65 houses from RT 05 (sub-village)
Time of survey	July 2011 April 2012

PRE-DISASTER CONDITION

17 months after the earthquake and tsunami in Aceh and Nias in 2004, the Indonesian society had just recovered from critical experience handling with disaster then suddenly came another disaster in 2006. An earthquake with a magnitude of 6.3 on the Richter scale struck near the city of Yogyakarta in Java Island on 27 May 2006 caused extremely and widespread destruction. The shallowness of the quake's epicentre contributed to widespread structural damage to the built fabric. Villages located in remote areas south of Yogyakarta were affected and more than 1,100,000 people were homeless. The national government and international humanitarian organisation had to act quickly distributing basic needs, medical treats and disaster relief. With a density of around 2,000 inhabitants/km the situation turns into a largely shelter crisis in Yogyakarta, Bantul and areas part of Central Java province. Other fact of the Yogyakarta special province locates in the middle of Central Java and it is a positive value that the infrastructure support system had already been designed as well as the mitigation system had already run properly based on the previously experiences with disasters. Although the crisis that time the local government together with the society can handle the hazard situation better than the Aceh earthquake.

POST-DISASTER RESPONSE PHASES

There are three significantly stages after the Yogyakarta earthquake in the Ngibikan. Villager had been built in order to cope their resiliency after the disaster:

Table 3
The three phases after disaster response in Ngibikan village

Immediate response	Early phase of reconstruction	Long-term development
During May-July 2006	***One week after the quake***	***After housing occupancy***
- Critical phase - Distribution of food, clean water and tents - Rescued victims - Tended the injured persons - Cleared rubbles - Began setting up tents	- Preparation to rebuild the permanent housing - Design and planning discussion, materials selection and supply, working methods - Building the working-groups - In August 2006, partly units were ready for occupancy.	- Connect to the macro-infrastructure system to outer village - Building mitigation system in the village-level - Legal documents process - Managing and improving the house

Phase 1: The immediate response

In the early period after disaster, an immediate action aims to stabilize the situation because of the aftershock. It was a critical time ensuring the community to reach good food, clean water supply, medical health assistance and tents. In case of earthquake disaster because of the ground-shakes, the clean water resources can be broke or disturbed e.g. the ground water level drops and the quality is getting worse, so that in this situation people have minimum

access to get adequate water. Otherwise, for safety-guarantee the electricity was shut down for a while. The situation with a minimum infrastructure supports generate a crisis.

Phase 2: The early phase of reconstruction
The early phase of reconstruction had high priority in rebuilding the permanent house than providing a temporary housing. Obviously, the reconstruction planning depended on that the development of the earthquake, which the hazard conditions could be handled in the immediate phase as soon as possible and a funding support. Besides, in the small village, they have a degree of collective sense and solidarity to face the same problem. It is a culturally aspect with a traditional community in Java that the villager origins mostly come from one big family-tree. This phase should be as quick as possible considering the next rainy season in this region.

Phase 3: The long-term development
People plan to raise their resiliency if probably the similar disaster comes again to them. The whole plan in the village-scale should connect to the sub-region plan (kelurahan, kecamatan, kabupaten). It is important in order to build the disaster risk management (response, preparedness, mitigation, reduction)

SPATIAL MODIFICATIONS

The core-house design is a result of the community agreement. This case study is possibly an exception from other reconstruction project in Bantul Yogyakarta and other region in Central-Java, because some men in this village have occupation as builder/workman or have experiences in building and hand working. As a social capital, this fact help them to realize the reconstruction process with their own methods and involved the collective working. Some agreements can be described as follow:

- A big family with more than one household (families) will receive houses base on the household numbers, but the houses will be built on the same land as before with a modified design arrangement.
- A family household, whose house destroyed, get one unit post-reconstructed house.
- A house with minimum standard of space in this case means the house is owned only one person, because at that time there was an old woman who stayed alone with no family.



Figure 4 Modification house for more than one family households [see.Figure 6 (a2)]



Figure 5 Modification house for one family household [see Figure 6 (b)]with a porch in front of the front-house

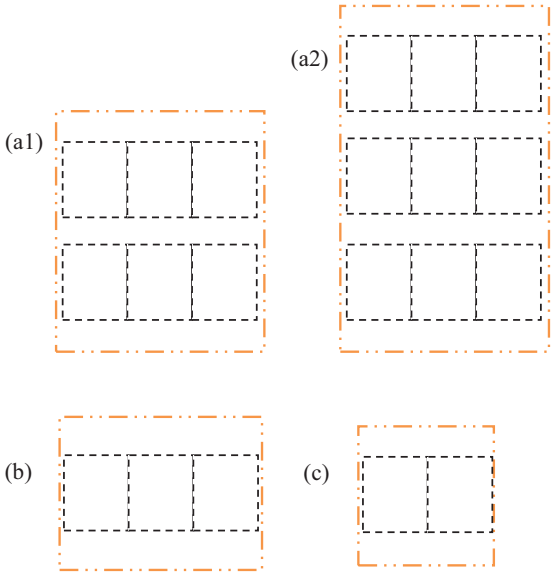


Figure 6 Typically core-modules with different requirements for the residents:

(a1) and (a2): more than one family households
(b) one family household
(c)a special case; a house for one person

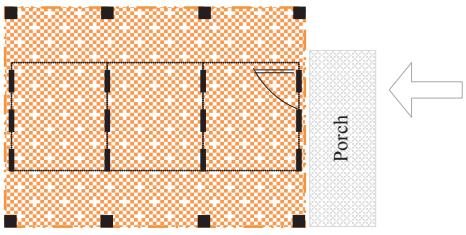
The design concept was inspired from the rural architecture: limasan. The commonly *limasan has* a vernacular hip roof with a peak on top. This house type characteristic consists of high-pitched vertical frame as the main form of the building (Shim, 2010). Other characteristics include an interior layout that has no permanent partitions and the wooden columns form the interior spaces. The main idea for the plan layout of the new design is following the core structure of limasan. Otherwise the dynamic in family growth is a consideration in designing the

core-house. With the suggested the core-module house, every family still has the opportunity to create their own identity, spatially and aesthetically. It seems the same design, but they can personalize the house with many strategies. Their approaches are based on their cultural manage and economically reason. Some strategies intends to save the construction costs, for example using the old fundaments for the new fundaments for the new house but it strongly must be considered in the capacity of the old fundaments. Moreover, applying old windows-and doors wooden frames expects for reducing the materials costs.



Figure 7 Applying old window and door wooden frame attached to the new house

The core-house is similar to 6x7.2 m^2. Because the owner is permitted to maintain the house, at the end each houses represents the expressions of needs and expectations of the house owner for the new house. But in common the house consists of the minimum aspects of space requirements. In general the house contains of the front, the back house and a trasition space/entrance. A transition space is frequently associated with a terrace or a porch. According to Revianto (1997), the residents' spaces cognition of front or back of the house that is usually associated to the hidden or shown area to other. Based on the local-culture knowledge the front house should express the statue of the home owner, so that commonly seen that in traditional houses in rural area, a terrace/porch functions for public uses, but a living room function for semi-private use for example to talk with the guest personally or in a private means and in the daily life. But in special ocassions (e.g. wedding party, birth and funeral) the spatial functions will be strongly different. It is common organizing cultural events, celebration of baby birth and funeral ceremony at home.



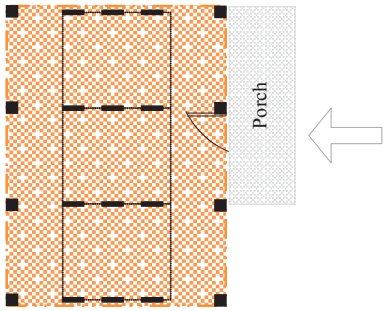


Figure 8 Typical modification-outcomes on adjusting entrance/ front door

Commonly there are two typical modifications in adjusting the entrance doors, specifically at the length side and the width side. The modifications depend on the site forms of the land and also it is based on the capability of the owner to identify their spatial uses. Because of the tropical climate in Indonesia the usage of terrace is very important and not only has as a cultural background concerning with the public and the private spaces. The long eaves roof in front of the front door can reduce the glare of the sun lighting and also providing a good shelter for the front door/entrance from rain splashing in the rainy season.

According to the research observation and interviews, the development processes of the houses mostly pursue the owner demand. After deciding the placement of the entrance door then some other adjustments will be added:

- A terrace/ a porch with expanded roof or adding pavement floor with no roof.
- An outdoor kitchen functions as a preparation place. An outdoor kitchen came from the traditional cooking habits in past using the wood stove/charcoal and mostly in rural area some families still cook using the wood stove/charcoal.
- Storehouse or cattle stall.
- An open carport for vehicles parking. Some wealhty families who can own a car or possess a motorcycle or more build an open or semi permanent carport to load the vehicles.

The development of houses can be summarized as follows:

Table 4
The degree of adjusment in the development of reconstructed-housing

	indoor	**outdoor**
Simple adjustment	Maintain or replacing the floor materials and paint colours	Adjusting extended floor for transition-space (porch/terrace)

Regular adjustment	Inserting room partitions or switching the room functions without any approaches.	- Placing doors and windows aacording to functions - Using old-wooden boards for covering the roof-vent
Rearrangements	Interior rearrangement which posibility replacing the roof structure.	Adding rooms outside the house and connect it to the main-house

Simple adjusments are commonly doing by the house owner and mostly it does not need a special workman. In the reconstruction project more villagers had been trained working in building so that they had construction skills used self-help constructionand some building maintenances can be done by the owner and neighbourhood. Regular adjustments are an open options for house-owner to personalize their need and to fit in with their space's cognitions based on community own behaviour and local culture. The possibility to actualize their personal identity gives positive impacts to the inhabitants. Regular adjustments are usually decided while in the designing and planning process and it can be also after occupancy process. After the program ends the user itself evaluates and adjusts to the new housing conditions spatially. So that they can adapt to their needs and preferences. Rearrangements indoor and ooutdoor could be taken years after the formal occupancy. Normally this adjustments are lack of assistance in planning and construction. House-owner can hire construction worker or having relatives and neighbourhoods help in construction. A guidance in expanding the core-house is needed to ensure the growth of new buildings of the provision to the earthquake resistant buildings.

SUMMARY AND CONCLUSIONS

After a hazardous disaster like an earthquake, people expects to access the safe condition to heal the fears immediately. The devastation of the buildings and the houses during the quake raises the need of adequate shelter in a short time. This situation leads to the settlement crisis after disaster. The vulnerability situation will increase in the duration of time if there is no intervention to raise the resiliency of the victims, for example supplying sufficiently food and clean water, mantaining the injured people with medical aids and providing shelters/tents. The degree of vulnerability depends on many factors, an example is the location factor. The densely population with poorly constructed building will raise the damages and also bring higher fatalities. A reconstruction is a consequence of humanitarian actions to recover and to build the life back. Although the definition of reconstruction or rebuilding itself still developes, but the key concerns in rebuilding aims to raise the resiliency of the community/victims better handling to face the similar disaster in the next future. The term of preparedness is highlighted in disasater management in order to planning and designing the environment/community better prepared to disaster. The duration of a project in a reconstruction is highlighted as a key concern to value a good project. The factor relates not only with the project cost but also in order to meet the victims' interest to get a safe condition.

In the case study of Ngibikan reconstruction, duration of a project gives directly a good effect on the successful of the project. Providing a good permanent houses based on the community's expectations and demands come in priority. The planning and designing the house can involve the community members, so that the residents have greater respects and sense of belonging to the future houses. But this situation depends indeed on the cultural manner of region. The Ngibikan project may become one the successful case in satisfiying and fulfilling of the inhabitants on valuing a good reconstruction project. Other side they had great participations in doing the rebuilding because 100% residents are owner the houses and also the land tittle. The sub village-leader as a project leader is good known and a trustworthy person among the community. Other interesting results of this case that the leader can wake the initiative of the community to rebuild the damaged houses earlier than the government program and of course through financial support they received from local donor. Within the collective working groups, villager discussion and working capabilities the leader manages it well. The small scale project allows the leader to set up in more details; the difficulty in supplying construction and building materials can be handled properly.

The selection of building materials is an important aspect in the reconstruction project. Not only because it should be contructively-earthquake safety but also can be accessed as good as possible from the village in the post-disaster period. In order to create comfort units some considerations are included; the availability of funds, the ability of the community in the future as well as maintenance in accordance with local climatic conditions. The unit cost implies not too be expensive. Reuses of existing facilities give more challenges, which can be integrated into unit design and settlement layout in order to establish a cost effective project. Reusing of materials in a new design settlement has become possible if the project is a small scale and the community has accepted. In the contrary to the participatory initiave, the top-down scheme is important if the shelter must be provided as fast as possible, while enabling residents to help themselves. Another signifiant aspect to build sense of belonging to the benificiaries is to identify

what participations could be self-managed by the residents to ensure a best-suited settlement according to its local cultural and climatic conditions.

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THE IMPACT OF CLIMATE CHANGE ON THE ENVELOPE PERFORMANCE OF COMMERCIAL OFFICE BUILDINGS IN SINGAPORE

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ABSTRACT

The objective of this study is to evaluate the impact of climate change on the conduction gain and the solar heat gain of commercial office buildings in Singapore using calculation models that have considered the impact of local urban microclimate. Focusing on the Singapore's CBD area, the results are shown in an integration of temperature map of the study area with the increase of conduction gain or solar heat gain in each of the studied buildings. It is found that climate change has more impact on the conduction gain into the buildings. Mitigation strategies are then proposed to reduce this heat gain. From the observation, recommendations are suggested to improve the envelope performance of commercial office buildings in Singapore.

INTRODUCTION

The increasing of urbanization causes higher temperature recorded in cities than in their non-urbanized surroundings, known as Urban Heat Island (UHI) (Oke, 1982; Jusuf, Wong, Hagen, Anggoro & Yan, 2007). Higher temperatures result in increased heat conducted through a building's envelope, thus increasing cooling energy in a building. In addition, the impact of shading due to surrounding urban morphology on solar heat gain through glazing is usually not accounted for when evaluation building performance. Methodology and model to calculate the conduction gain and the solar heat gain of commercial building envelope considering the effect of UHI and the impact of shading for Singapore climate were developed.

Climate change will affect the building envelope performance. It will change the amount of conduction gain and solar heat gain into the buildings. Using the previously mentioned developed methodology and model, the impact of climate change on the conduction gain and the solar heat gain of commercial office buildings in Singapore is evaluated. Mitigation strategies are then proposed to reduce the heat gain into buildings.

The development of methodology and model to calculate the conduction gain and the solar heat gain considering the local urban microclimate is discussed briefly. It includes the development of local outdoor air temperature calculation which takes into account the impact of UHI effect on envelope performance, conduction gain through exterior surfaces, incident solar radiation and solar heat gain calculation. This paper focuses more into the evaluation of the impact of climate change on the envelope performance, and is restricted to commercial office buildings in Singapore's Central Business District (CBD).

METHODOLOGY

Projected weather data

The weather data used in the study were provided by Institute of Higher Performance Computing (IHPC) of Singapore which included the observed weather data (as base case) and three different time frames of future projected weather data (namely Period 1, Period 2 and Period 3). The projected weather data for Period 1, Period 2 and Period 3 shows an average air temperature increase of 0.50°C, 1.30°C and 2.40°C respectively.

Envelope performance assessment model and methodology

Local outdoor air temperature calculation

The projected weather data provided has not taken into account the impact of UHI effect. Therefore, an empirical model was used to morph the output of STEVE Tool model into a 24-hour profile to predict the performance of a building's enclosure.

The empirical model was developed by comparing a field measurement data in the CBD area with the air temperature predicted by STEVE Tool using the recorded weather data.

The STEVE Tool model is an air temperature prediction models developed using empirical data collected to evaluate the impact of estate development (Wong, et.al., 2007) in Singapore climate. The model uses the weather data and the urban morphology conditions to generate maximum, average and minimum air temperature in an estate.

Conduction gain through exterior surfaces

Conduction through exterior walls, windows and roofs is calculated using the sol-air temperature in conjunction with the conduction equation. A

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comparative approach is used to simplify the process of evaluating the envelope performance where the change in conduction gain was used instead of conduction gain itself.

Incident solar radiation
Solar radiation incident on building surfaces can be broken down into three components, i.e. the beam or direct radiation, the diffuse sky radiation and the ground reflected radiation. The global radiation data provided from the weather data are separated into direct and diffuse components. These direct and diffuse horizontal radiation fluxes are then used to calculate each of the three components that are incident on every external building surface.

Solar heat gain calculation
The transmitted solar radiation depends on the amount of incident solar radiation. It is computed at ten degree intervals for hourly time steps for the entire year.

Temperature map

Temperature map of an estate's environmental condition is generated using the STEVE Tool model. It takes into account the climate predictors such as daily minimum temperature, daily average temperature, daily maximum temperature and average of daily solar radiation from weather data, and the urban morphology predictors such as pavement area over surface area, height to building area ratio, wall surface area, green plot ratio, Sky View Factor (SVF) and surface albedo.

Building envelope performance

To provide an overview of an estate's environmental condition as well as the envelope performance of buildings within the estate, the average temperature map is integrated with calculations for conduction gains and solar heat gains. To illustrate, 8 buildings in the CBD area were selected as shown in Figure 1. Using detailed material and construction data on each of the building's façade provided by the Building and Construction Authority (BCA) of Singapore, the increase in conduction heat gains and the window solar heat gains were calculated. The calculated heat gains were then normalized by dividing by their respective envelope area.

This was done for the three different time frames to evaluate the impact of climate change. The results are shown in an integration of average temperature map of the area with the normalized increase in conduction gain or solar heat gain for each Period. Higher increase in heat gain that reflects poorer building envelope performance is shown in darker red colour, while lower increase is shown in lighter yellow colour.

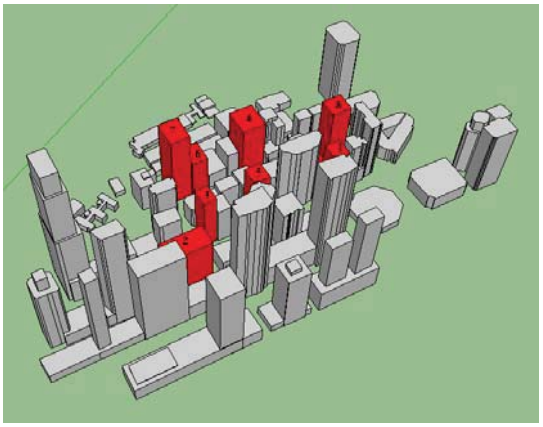


Figure 1 Dimensional model of buildings 1 to 8 and their surrounding built environment

Mitigation strategies

Mitigation strategy 1 proposes to increase greenery density by planting trees along walkways in dense built up areas. The trees are assumed to be matured trees with Leaf Area Index (LAI) of 4 and a crown size of 6 meters. In this scenario, the trees were planted wherever possible, with minimum distance between them to maximize greenery density around the 8 buildings.

Mitigation strategy 2 assumes that the 8 buildings have opaque walls with 100% greenery coverage and windows using double glazed unit with a combination of reflective coating and a pane of low-emissivity glass. Turfing was used to cover the opaque walls. Based on measurement data from a previous study conducted in Singapore (Wong et al., 2003), the thermal resistance of turfing is 0.36 m^2K/W while the K-value of the 0.04m thick substrate is 0.144W/mK. Specification of glazing was obtained from catalogue that is used in Singapore. The double glazed unit has a 6-16-4 mm configuration. It comprises an outside blue tinted glass, 6mm thick, with a reflective coating in position, and assembled with an inside pane of low-emissivity glass of 4mm thick. The 16mm space between the two panes is filled with argon. The unit is hermetically sealed with a flexible double seal. This combination produces a double glazed unit with a glazing U-value of 1.1 W/m^2K and a Solar Heat Gain Coefficient (SHGC) of 0.174.

IMPACT OF CLIMATE CHANGE

Figure 2, Figure 3 and Figure 4 show the average temperature map integrated with the normalized increase in conduction gain for Period 1, Period 2 and Period 3 respectively.

Based on observation, it can be seen that the increase in conduction gain is relatively mild in Period 1 and

increases over the years as ambient air temperatures increases due to the climate change. This is evident from the change in colours of the temperature map from blue in Period 1 to mostly yellow in Period 2 to orange/ red in Period 3. However, although the average ambient temperature increases, not all buildings experience the same increase in conduction gain. This may be due to the surrounding morphology or the envelope construction of the building.

Buildings 5, 6, and 8 have relatively poorer performance in conduction gain amongst the 8 buildings, with building 5 performs the worst. As air temperature increases from Period 1 to Period 3, these three buildings illustrate colours that change more drastically from yellow to red across the maps.

Besides building 8 which has a higher average air temperature due to its surrounding morphology, the greater increase in conduction heat gain at buildings 5 and 6 is most probably due to poor thermal resistance. A look into the construction materials shows that the U-value (walls and windows) of buildings 5 and 6 averages at (2.71 W/m²K and 5.8 W/m²K) and (2.63 W/m²K and 1.6 W/m²K) respectively, which are relatively higher than the U-value of the other buildings which generally falls below 1.

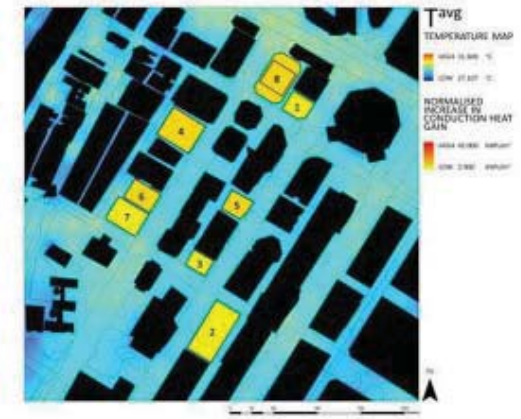


Figure 2 Normalized increase in conduction heat gain for Period 1

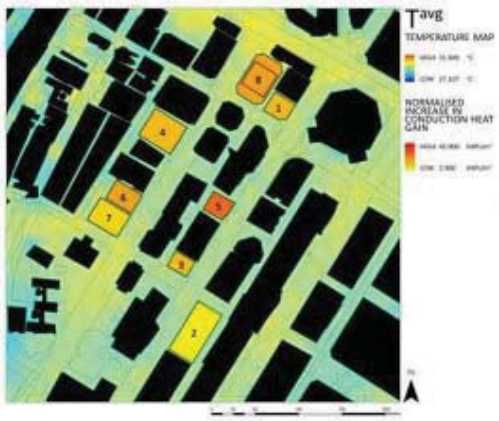


Figure 3 Normalized increase in conduction heat gain for Period 2

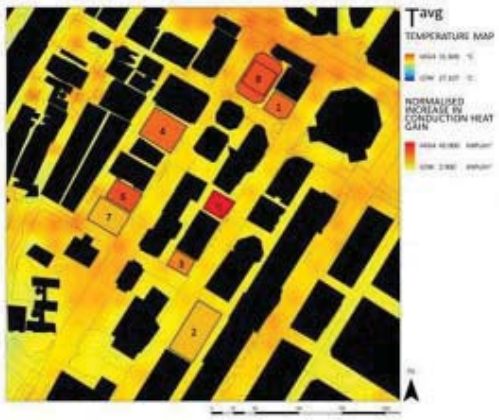


Figure 4 Normalized increase in conduction heat gain for Period 3

Figure 5, Figure 6 and Figure 7 show that window solar gain remains relatively constant from Period 1 to Period 2 to Period 3. It is reasonable since global solar radiation remains relatively constant across the projections, decreasing slightly over each projection period. This decrease may be due to an increase in greenhouse particles in the atmosphere (Santamouris et al., 2001). Green house particles reflect solar radiation, leading to a decrease in the solar energy that reaches building surfaces and therefore decreases the solar heat gain by buildings.

It can be seen that building 5 also has the worst performance when evaluated by solar heat gain through glazing. This is despite being located at a densely built up area which provides significant shading from direct incoming solar radiation. Hence the high solar heat gain can be attributed to the type of glazing used, i.e. an 8mm tinted heat strengthened single glaze with a high SHGC of 0.83.

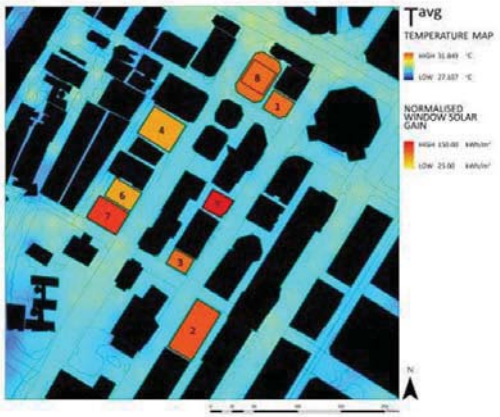


Figure 5 Normalized window solar gain for Period 1

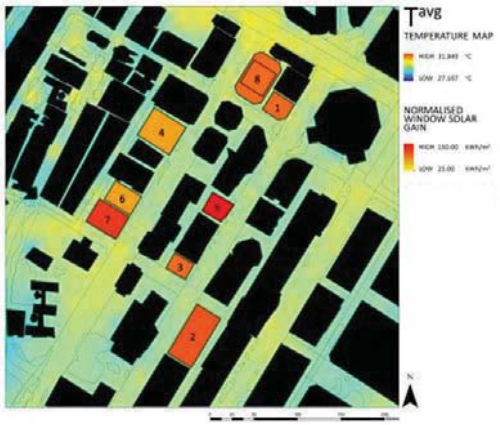


Figure 6 Normalized window solar gain for Period 2

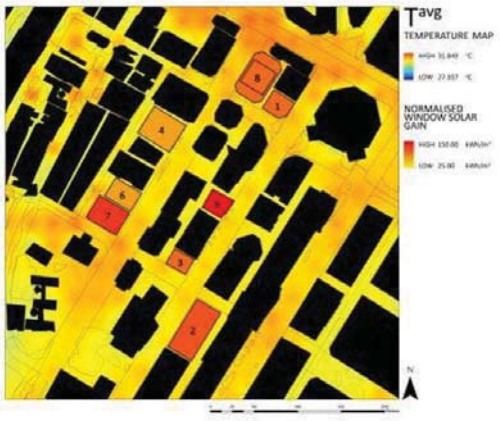


Figure 7 Normalized window solar gain for Period 3

MITIGATION STRATEGIES

From the evaluation on the impact of climate change, it can be seen that climate change has more impact on the conduction gain into buildings due to the increase of air temperature. Therefore, the mitigation strategies proposed focuses more on how to reduce the ambient air temperature. Two strategies evaluated are by increasing greenery density by planting trees along walkways in dense built up areas (mitigation strategy 1) and 100% greenery coverage on opaque walls and improved glazing (mitigation strategy 2).

Mitigation strategy 1

Figure 8, Figure 9 and Figure 10 show the normalized increase in conduction heat gain with tree planting for Period 1, Period 2 and Period 3 respectively. It can be observed that tree planting does not have significant effect in alleviating the increase in conduction heat gain due to climate change. One possible reason is because in a densely built up area, the surrounding buildings have provided significant shading such that the presence of trees does not provide additional shades, but only reduces the impact of climate change effect via the process of evapotranspiration.

The only significant impact that can be observed is the improvement in envelope performance of building 8 in Figure 9 and Figure 10. This is because building 8 is located at an area where the average ambient temperature is higher than that of the other buildings. As a result, increasing greenery density around it has a greater effect in reducing average temperatures than around buildings 1 to 7.

Hence, it can be concluded that the planting of trees around open areas covered with highly heat absorbant pavements would have greater impact in alleveating the increase in conduction heat gain due to climate change as compared to within densely built up urban centres.

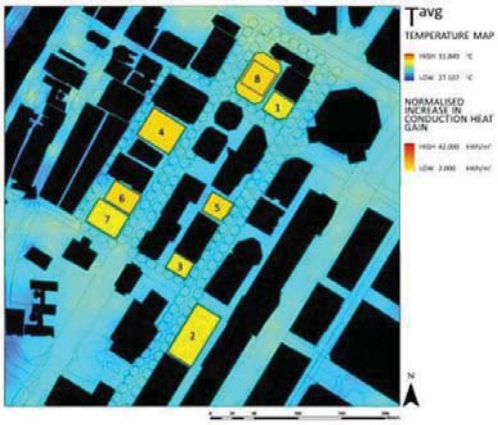


Figure 8 Normalized increase in conduction heat gain with tree planting for Period 1

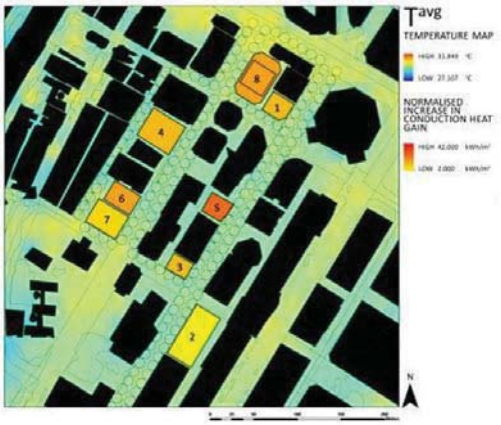


Figure 9 Normalized increase in conduction heat gain with tree planting for Period 2

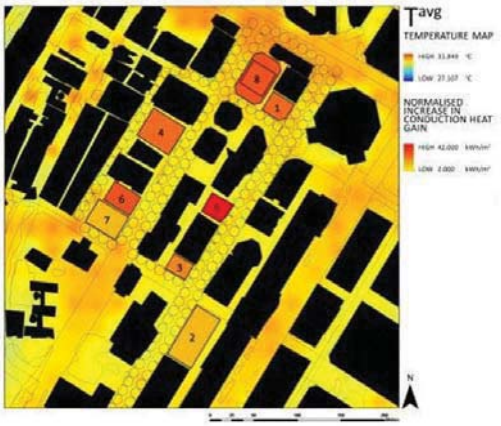


Figure 10 Normalized increase in conduction heat gain with tree planting for Period 3

Mitigation strategy 2

Since planting trees around the vicinity of buildings in a densely built up urban area is not an effective mitigation strategy for climate change, the solution needs to be applied to the building's façade instead. In this scenario, the 8 buildings are assumed to have opaque walls with 100% greenery coverage and windows using double glazed unit with a combination of reflective coating and a pane of low-emissivity glass.

Figure 11, Figure 12 and Figure 13 show the normalized increase in conduction heat gain, while Figure 14, Figure 15 and Figure 16 show the normalized window solar heat gain for the three different time frames. It can be observed that implementing 100% greenery coverage over opaque walls together with improved glazing performance can significantly improve envelope performance as seen by the yellow colour of all 8 buildings in all three temperature maps. This tells us that mitigation strategy 2 is more effective.

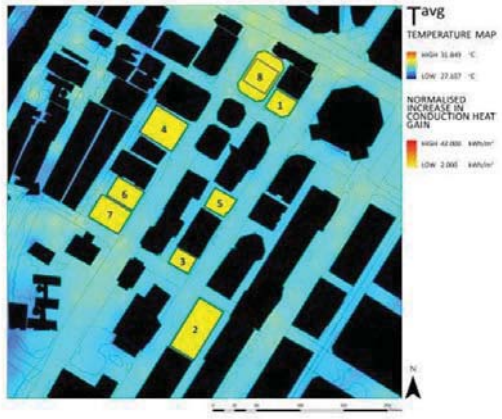


Figure 11 Normalized increase in conduction heat gain with strategy 2 for Period 1

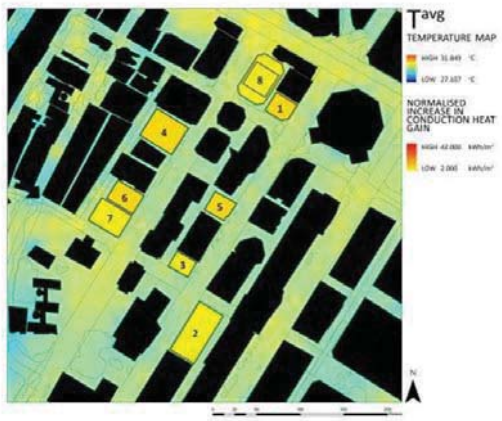


Figure 12 Normalized increase in conduction heat gain with strategy 2 for Period 2

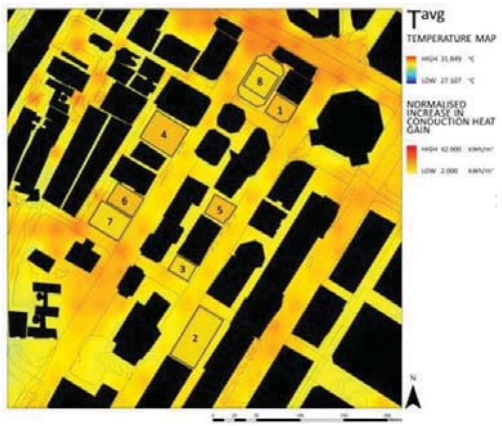


Figure 13 Normalized increase in conduction heat gain with strategy 2 for Period 3

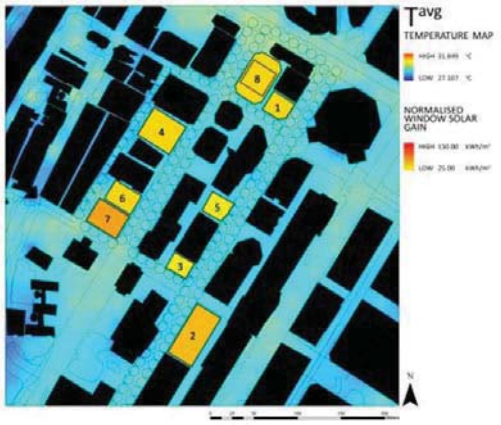


Figure 14 Normalized window solar gain with strategy 2 for Period 1

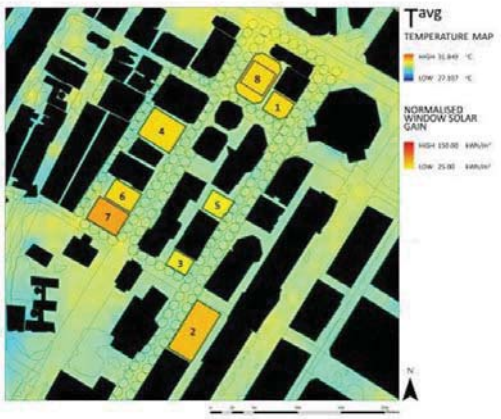


Figure 15 Normalized window solar gain with strategy 2 for Period 2

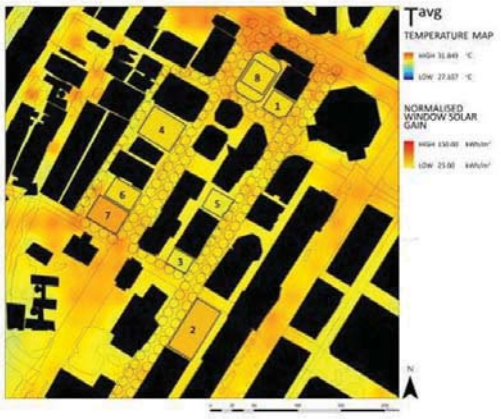


Figure 16 Normalized window solar gain with strategy 2 for Period 3

Table 1 further shows that using vertical greenery is able to mitigate the increase in conduction heat gain through opaque walls by between 18% to 63% depending on the existing thermal resistance and WWR of buildings 1 to 8. Accumulatively, having vertical greenery would mitigate this increase of all 8 buildings by 55%. The use of better glazing also has the potential to mitigate the increase in conduction heat gain (due climate change in Period 3) through glazing of all 8 buildings by 59%. Furthermore, the use of better glazing is able to reduce solar heat gain through glazing by between 36% to 80% depending on the SHGC of existing glazing as well as the window-to-wall ratio (WWR) of the buildings. These adds up to a 53% reduction in window solar heat gain when all 8 buildings are considered cummulatively.

From this study, it can be seen that there is much room for improving the envelope performance of commercial office building in dense urban areas in Singapore and the implementation of vertical greenery as well as better performing glazing is able to significantly alleviate the UHI effect as well as reduce solar heat gain in buildings.

Table 1
Percentage reductions in each respective gain with 100% greenery coverage and improved glazing for Period 3

BUILDING NO.	PERCENTAGE REDUCTION		
	Δ WALL CONDUCTION GAIN	Δ WINDOW CONDUCTION GAIN	SOLAR GAIN
1	60%	44%	43%
2	18%	22%	36%
3	25%	70%	61%
4	60%	32%	40%
5	63%	80%	80%
6	62%	27%	40%
7	33%	30%	42%
8	30%	80%	56%
Total	55%	59%	53%

CONCLUSION

The envelope performance of commercial office buildings in Singapore's CBD area and the impact of climate change on it have been evaluated by the increase in conduction gain due to UHI effect and the solar heat gain through windows which has considered the effect of shading by surrounding buildings and morphology. The separation of conduction gains from solar heat gains also helps in identifying the areas of the building facades that requires the most attention.

The increase of air temperature due to climate change will increase the conduction heat gain into buildings which have been shown by the temperature maps.

Based on the observations and analysis of the temperature maps of the CBD area, several conclusions and recommendations are made as follows.

Reducing SVF has the effect of reducing maximum temperature since a reduction in view of the sky would mean the surface receives less solar radiation during the day. Such dense built up areas usually have large wall surface areas, providing more surfaces for heat absorption and leading to higher stored energy and hence, increasing temperatures in urban centres. Therefore, a low SVF also results in higher night-time temperature due to reduced radiant heat loss to the sky. This is the characteristic of UHI effect.

Trees and green spaces such as parks and clusters of trees contribute significantly to the cooling of cities. They not only provide solar shading in the day, but also reduce air temperature through the process of evapotranspiration, thus cooling the area throughout the day.

Tree planting around air-conditioned buildings with poor envelope thermal resistance and situated in open areas covered hard heat absorbing surfaces should be prioritized to provide shades that can reduce increases in air temperature.

For buildings situated in dense urban settings, the priority measures should be on improving thermal resistance locally. This is because with a low SVF, providing additional shading with trees adds minimal benefits. Better glazing with low SHGC or g-value should be emphasized for all air-conditioned buildings, given the abundant solar radiation incident on building surfaces in Singapore all year round. Better performing glazing and implementation of vertical greenery will be able to significantly alleviate the UHI effect as well as to reduce solar heat gain in buildings.

ACKNOWLEDGEMENT

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A COST MANAGEMENT APPROACH TO SUSTAINABLE CONSTRUCTION; MAXIMIZING VALUE VIA COST ENGINEERING TECHNIQUES

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ABSTRACT

This paper presents a schematic flow for managing LCC-oriented costs throughout a building's life cycle from a cost management perspective. It provides case studies and identifies trends of various cost engineering methodologies, including managing green cost premiums and incremental costs for Green Mark buildings in Singapore. LCC cyclical replacement as well as RElifing®, a quantitative-based analytical tool for economical and sustainability decisions, will be discussed. These tools illustrate application of the cost management approach in order to achieve an economic accounting at various stages of a building's life-span.

INTRODUCTION

Background

A sustainable built environment is often perceived as a panacea for resource strain, as the building and construction industry offers immense potential for sustainability efforts, due to its high level of energy consumption and waste production (IPCC, 2007).

In the United States, more than 7 million residential units were built between year 2005 and 2009 (U.S. HUD, 2008), and approximately 170,000 commercial buildings are constructed annually (US Censor Bureau, 2002).

Locally, the relatively large existing building stock of 210 million m^2 contributes to almost half of the nation's electricity consumption (BCA, 2011), which is a significant percentage for a small and densely populated country of approximately 707 km^2 with a population of 4.99 million people.

It is evident that building and construction products have a large socio-economical relevance (Ortiz *et al*., 2009) as the activities in the sector have both high initial and follow-up expenditures, long life cycles and they require significantly large amounts of materials, energy (Nemry *et al*., 2010), and associated monetary costs.

Research problem

The local authorities recognised the need for sustainable construction and various schemes and legislations have been introduced, including the Green Mark (GM). Since FY2005, the cumulative building Gross Floor Area (GFA) under the Green Mark Scheme has been steadily on the rise, from 1.1 million m^2 in FY2005, 2.1 million m^2 in FY2006, 5.7 million m^2 in FY2007, 10.0 million m^2 in FY2008, 15.4 million m^2 in FY2009 to 20.0 million m^2 in FY2010. There are currently more than 750 Green Mark building projects in Singapore.

However, there is still a long way from the Building and Construction Authority's (BCA) 2030 target of having 80% of existing buildings 'green'. A significant challenge faced by sustainable construction advocacy is the widespread perception that these buildings – and their associated installation costs – are substantially higher than conventional designs, thereby causing apprehension and inertia to many developers.

While local legislations, in particular the Building Control (Environmental sustainability) Regulations 2008, have made compulsory the attainment of a minimal Green Mark certification for developments with Gross Floor Area (GFA) larger than 2,000 m^2, many building owners merely comply with the minimum required score for the respective Green Mark awards, without considerations for life-cycle costs and impact.

In order to encourage building owners to achieve higher Green Mark scores and to minimising life cycle impact of buildings during both new building construction and additions and alterations (A&A) programmes, it is essential to establish accurately the cost implications incurred and higher value that sustainable buildings confer. In addition, while general indicative green cost premiums for higher Green Mark ratings have been published, there are limited studies on the detailed cost and life cycle replacement cost implications. Moreover, while the proliferation of green building councils (GBCs) and green building certification programs around the world serve to exhibit the widespread embracement of green buildings, recent trends suggest focus on green design solutions, possibly overlooking the potential contribution from other relevant areas.

This study, done in the local context, focuses on the economical aspects of sustainable building and construction, with the purpose of maximizing value in sustainable construction via cost engineering techniques.

LITERATURE REVIEW

LCC-oriented cost engineering techniques

Life cycle costing (LCC) was originally not developed in an environmental context (Gluch & Baumann, 2004), but a type of investment stimulus (Sterner, 2002) used to rank varying investment

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alternatives (Kirk & Isola, 1995). 'Traditional' LCC techniques is an outgrowth and application of a branch of economics called 'theory of investments', which has an extensive literature (Stern, 1978). Stern (1978) further elaborated that LCC involved utilizing a consistent methodology to compare competing systems for procurement of a service by reducing the costs of ownership and operation to a single number, stated in terms of *present value*. LCC subsequently evolved, with its techniques placed in an environmental context. An example includes Aye *et al*.'s (2000) utilisation of LCC for analysing construction options for a building in Australia. Abraham and Dickinson (1998) studied the usage of LCC calculations to quantify building disposal costs. Sterner (2002) developed a model incorporating LCC calculation methodologies for tender, while Bogenstatter (2000) advocated the usability of performing LCC calcuations in early design phases of a project.

The Association of Cost Engineers (ACostE) defined cost engineering as the engineering practice "devoted to cost management, involving such activities as estimating, cost control, cost forecasting, investment appraisal and risk analysis", skillsets similar to those of Quantity Surveyors. These are tools typically employed in a construction project environment, with a fundamental focus on cost control and reduction instead of environmental considerations and benefits. However, sustainability involves balancing financial, human and natural resources for long-term benefits (EPA, 2013), thereby suggesting that these cost engineering tools, which recognises and focuses on the physical and cost aspects of construction projects (Greves & Journier, 2003), are synonymous and complementary to LCC techniques and could be utilised in tandem.

RElifing®

Gluch & Baumann (2004) revealed limitations in the adoption and application of the life cycle approach in the construction industry, while Kohler & Moffatt (2003) discussed variances in life cycle analysis methodologies across countries and organisations, subsequently suggesting that "the most environmental building is usually no building at all".

For example, if construction of a proposed clinic can be eliminated through policies and operations to provide people with health-care in their homes, or if adaptive reuse of existing under-utilised facilities can dismiss the need for office extensions, this would definitely be the preferable approach (Kohler & Moffatt, 2003). This prompted the necessity to identify viable options to extend the lives of existing buildings.

RElifing®, an RLB trademark registered in the United States, is a quantitative-based methodology to evaluate business decisions prior to upgrading/redevelopment, to determine the 'useful life' of a building. It does not seek to analyse the cost of replacing a building/facility with new buildings/facilities but rather, to determine whether it is worthwhile capturing the remaining value and thereby "extending the life of that particular building/facility". RElifing® uses 2 principal concepts:

1. Weighted average service life (WASL)
2. Intrinsic value

The roots of this technique can be traced back to 2002, when the State of Arizona was in the midst of a budget crunch and its legislators were sourcing for innovative ways to save costs. Rider Levett Bucknall Americas worked with the State to develop legislation based on the RElifing® methodology. RElifing® studies were subsequently conducted on 80 Arizona State buildings over a sixth-month period, with a resultant USD$26 million cost savings, together with enhanced development resource efficacy and sustainability for the state.

Gap in knowledge

The brief literature review shows that while many studies have been conducted on the application of LCC for sustainability in the built environment and construction industry, few of them focus on applying tradition and LCC-oriented cost engineering techniques in Singapore. This paper attempts to fill this gap by field-studying application of cost engineering techniques on local projects, applicable at various stages, i.e. pre-construction, post-construction and addition and alteration.

RESEARCH METHOD

Plan of approach

This study employs a myriad of cost engineering techniques associated to the profession of Cost Engineers and Quantity Surveyors, including cost estimating, cost planning and forecasting, facility auditing and life cycle costing for cyclical replacement for various stages of a building project. In addition, the application of the RElifing® technique in the local context was also studied. *Figure 1* illustrates the plan of approach.

Data collection

The discussion segment commences with a proposed cost management schematic flow from construction/procurement, operation and maintenance to replacement and/or disposal. The discussions in the subsequent chapters focus on cost engineering and management during construction, and before decision is taken to retrofit/replace building components.

For the initial capital cost segment, 15 buildings were random chosen from Rider Levett Buckall Singapore's project library and data were obtained from these buildings. Green Mark scores of these buildings, as well as the construction costs for before and after the finalized green implementations, were

tabulated. The cost differentials of the various criteria of the green mark scheme allow a cost analysis of the construction cost premium due to green implementations. The projects were assessed based on the Green Mark Scheme Version 4.0 for both residential and non-residential buildings. Common green installations and their associated costs were also identified.

A project was subsequently selected at random from the initial pool, with its building components and life expectancy information extracted and obtained from various sources, including the respective contracts. A 30-year cycle was adopted for the calculation of cyclical replacement costs, and the relevant costs were projected up to the end of the 30th year, for comparison with a base case, which is non-Green Mark certified.

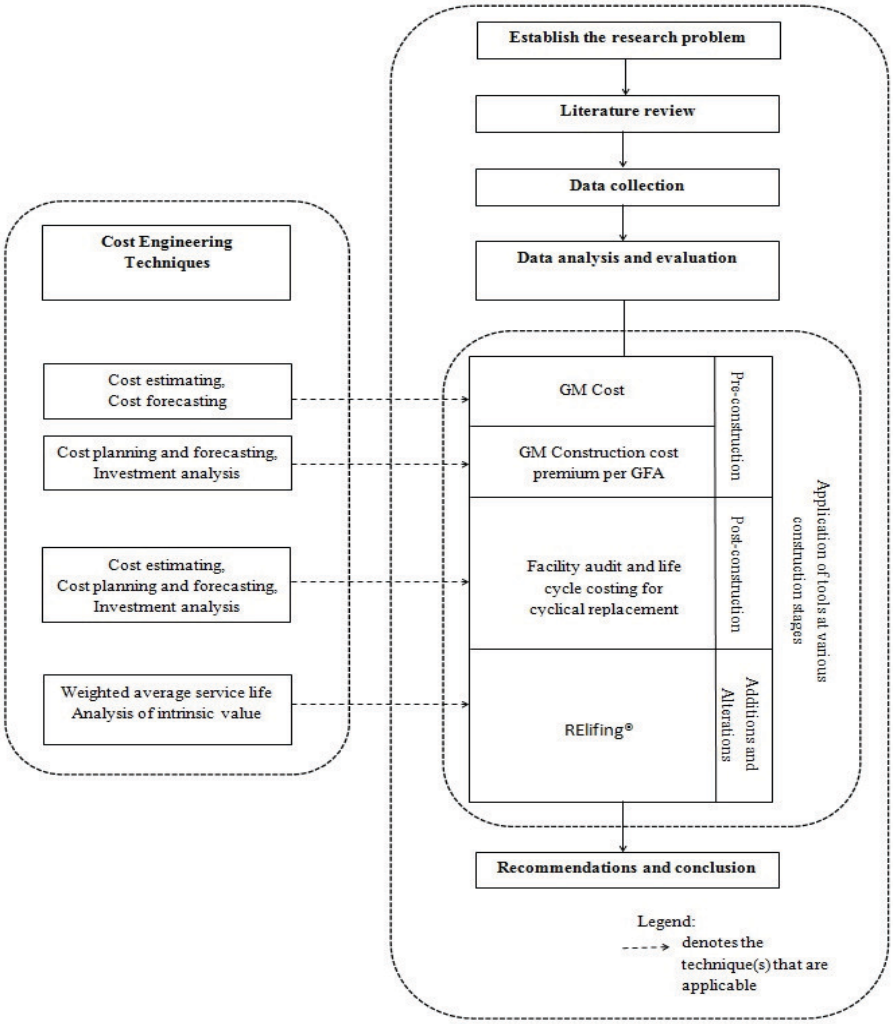


Figure 1 Plan of approach

RESULTS & DISCUSSION

Schematic flow of managing LCC-oriented costs

Selection of green products, installations and technology includes considerations for initial capital cost for acquisition/procurement, life span of product/feature, possible payback, discount rate, operational and maintenance costs, cyclical replacement costs as well as disposal costs. *Figure 2* shows the proposed schematic flow of managing LCC-oriented cost from a cost engineering and management perspective.

The initial capital costs include all costs associated with procurement, supply, delivery and installation of materials and products. An additional green cost premium may be incurred in order to achieve higher Green Mark score, depending on the selection of features and other factors – including, but not limited to, GFA, type of building, design scope and targeted Green Mark rating. The next section of this paper discusses the general cost trends and green cost premiums necessary to achieve incremental improvements in the Green Mark ratings. In addition to capital costs, LCC-oriented cost management

requires accurate analysis of discount rate trends of the committed capital as well as the life span of the installations.

A LCC-oriented cost management approach also warrants analyses of operational and maintenance costs, factoring in possible payback periods upon evaluation. However, in-depth discussions of operational and maintenance costs and associated payback periods of green features and installations are beyond the scope of this paper. The subsequent sections will focus on managing cost-relevant decisions, and cost engineering for cyclical replacement and extension of building life (RElifing®) to capture – and maximise – its remaining value. Upon conclusion of RElifing®, facility auditing and assessment of cyclical replacement, considerations have to be made for disposal and replacement costs. At this regard, it is integral to note that each country is characterised by its own waste management tariff framework (Peri *et al*., 2004).

Green mark construction cost premium

Table 1 depicts the distribution of the randomly selected buildings, which consist of 6 residential and 9 non-residential buildings. The random sampling is not meant to be statistically analysed but rather, to illustrate the application of cost engineering techniques as well as identification of cost trends.

As observed from *Table 1*, there are a total of 1 GM Certified project, 8 GM Gold projects, 2 GM Gold^{plus} projects and 4 GM Platinum projects. The base construction cost for GM gold projects, including residential and non-residential, ranges from the lowest of \$2,239.75/m^2 to the highest of \$3,786.55/m^2. The GM Gold project with the highest base construction cost also has the highest additional capital cost for green features (\$88.49/m^2) and green cost premium: a 2% increase from the base construction cost to improve the GM rating from Certified to Gold. The lowest additional capital cost required for green features is \$12.75/m^2 with a resultant 0.4% green cost premium.

The additional capital cost for the 2 GM Gold^{plus} projects varies significantly, with \$45.41/m^2 (0.5%) for the project with a GFA of 14,000m^2 and \$89.18/m^2 (2.8%) for the larger project with a 33,000m^2 GFA. This could be attributed to the difference in scope and magnitude of the projects, exemplified by the significant difference in GFA and base construction costs. The GM Platinum projects witnessed a large variance in the additional capital cost required for green features as well, with the lowest being a cost of \$24.98/m^2 with 0.6% green cost premium and the highest being \$203.92/m^2 with 6.9% green cost premium.

Figure 3 shows the plot between green cost premium and Green Mark score for the random sample. As observed, apart from 2 projects, the non-residential buildings generally achieved higher Green Mark scores compared to residential buildings. The non-residential buildings generally achieved higher Green Mark scores for similar amount of green premium as well, especially in the region of \$20/m^2 to \$90/m^2. Owners/developers can utilise the green cost premiums to calculate the additional costs incurred due to the Green Mark score that they want to achieve. This allows them to make better cost estimates of the construction cost of their buildings, as well as informed decisions with respect to the payback periods of their buildings.

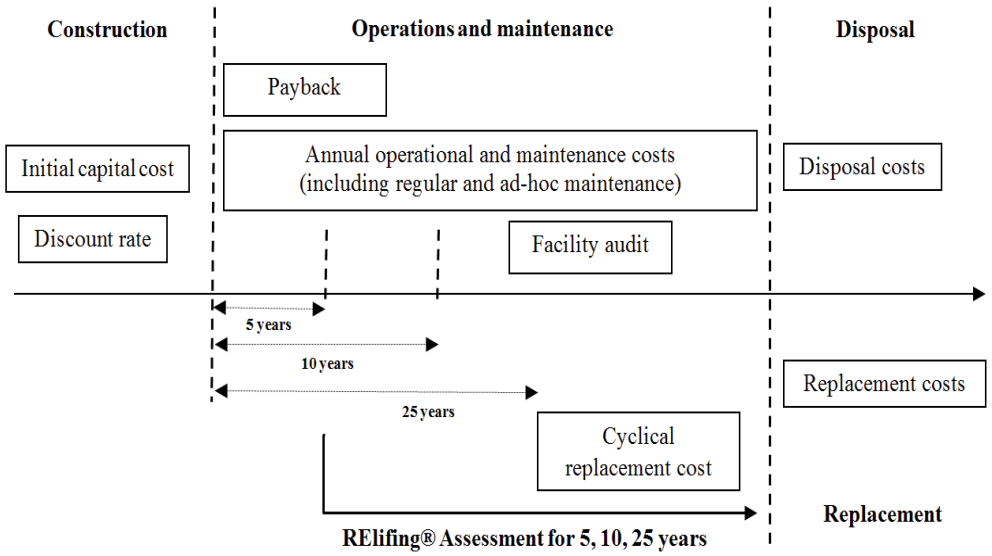


Figure 2 Proposed schematic flow of managing LCC-oriented costs for a building

Table 1
Green cost premium of sampled building

S/N	Building Type	Gross Floor Area (m^2) - nearest thousand	Green Mark	Base construction cost for Green Mark certified ($/$m^2$)	Addition capital cost for green features ($/$m^2$)	Green cost premium (%)
1	Residential	25,000	Gold	3,049.36	12.75	0.4
2	Non-residential	25,000	Platinum	2,768.26	63.16	2.3
3	Non-residential	14,000	Certified	1,081.81	0	0
4	Non-residential	10,000	Platinum	3,742.38	192.53	5.1
5	Non-residential	14,000	Gold^{plus}	9,278.23	45.41	0.5
6	Non-residential	33,000	Gold^{plus}	3,146.43	89.18	2.8
7	Non-residential	29,000	Platinum	4,410.41	24.98	0.6
8	Non-residential	19,000	Gold	2,909.84	22.83	0.8
9	Residential	42,000	Gold	3,786.55	88.49	2.0
10	Residential	48,000	Gold	2,813.01	19.55	0.7
11	Residential	27,100	Gold	3,117.40	39.59	1.3
12	Non-residential	25,000	Gold	2,239.75	16.00	0.7
13	Non-residential	47,000	Gold	3,744.25	18.94	0.51
14	Non-residential	13,000	Platinum	2,971.49	203.92	6.9
15	Residential	44,000	Gold	3,058.01	52.98	1.7

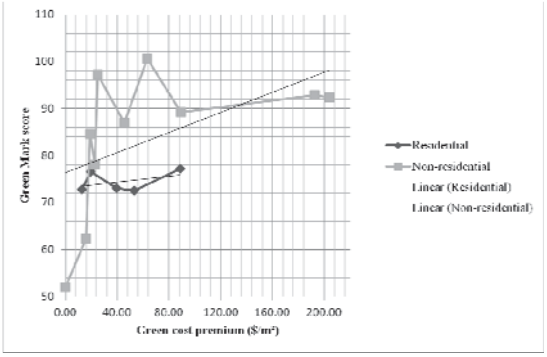


Figure 3 Green cost premium vs Green Mark score

Green costing

A myriad of green products and installations are available in the market from manufacturers and suppliers. New materials and technologies are constantly introduced as well (Wong & Li, 2008). The selection of green products and installations is a complex procedure and it is difficult to match materials based on design requirements alone (Ashby, *et al*., 2004). Products and materials are generally selected from existing catalogues, with experts applying the trial and and error method of selection based on experiences (Shanian & Savadogo, 2006), as with the local construction industy – which often base selection/procurement on (lowest) cost.

Table 2 provides an example of a summary of an indicative range of costs for various common green features utilised in projects obtained from the rates library of Rider Levett Bucknall Singapore. Having detailed cost information of installations and identification of areas of improvement in the Green Mark points matrix allows possible increase in points obtained with lower costs.

Table 2
Cost per unit for common green products/technology

S/N	Description	Unit	Unit rates (S$)
1	Energy efficiency		
a	Building-Integrated PV	Wp	10 to 30
b	Building Management System	point	300 to 400
c	LED Lighting	bulb	9 to 20
d	Photovoltaic (PV) Modules	Wp	8 to 12
e	Regenerative Lifts	no.	*6000 to 8500
2	Water efficiency		
a	Rainwater Harvesting	m^3	1000 to 1500
3	Environmental protection		
a	Green Concrete	m^3	140 to 160
b	Green Roof	m^2	150 to 350
d	Termite Treatment Mesh	m	55 to 60
4	Indoor environmental quality		
a	CO_2 Monitoring	no.	600 to 700
b	Engineered Timber Flooring	m^2	200 to 350
c	Green Carpet	m^2	50 to 75
d	Green Drywall Partition	m^2	65 to 75
e	Low VOC paint	m^2	2.5 to 4
f	Low emission glass	m^2	100 to 120
5	Other green features		
a	Pneumatic Refuse System	apt	1600 to 2500

* Additional cost per unit

Life cycle costing for cyclical replacement

Figure 4 and *Figure 5* show the projected cyclical replacement cost plots of the M&E systems for two different buildings over a 30-year period. From both figures, it was observed that the cyclical replacement cost of Building A is more varied compared to that of Building B – with the costs incurring on a more frequent basis. Building B is a Green Mark Platinum construction randomly selected from the list of 15 buildings in *Table 1* while Building A is a random project with approximately similar GFA, design intent and scope to serve as a base project for comparison.

The 30-year period is divided into three terms – short term (Years 1-3), medium term (Years 4-10) and long term (Years 11-30) as depicted by the different colours. Costs are incurred starting from the medium term for Building A, while most costs are incurred in the long term for Building B. The general payback period for a Green Mark Platinum building is between 2.5 to 6.5 years, according to the information published by the Singapore Green Building Council (SGBC). Building A requires more frequent replacements at smaller costs while for Building B, the first major replacement cost is incurred after the Year 15 – with the cost being significantly high. Owners/developers can project cyclical replacement costs for their buildings over a specified period of time, to provide an indication of the cost pattern and amount of money that they have to put aside for replacements.

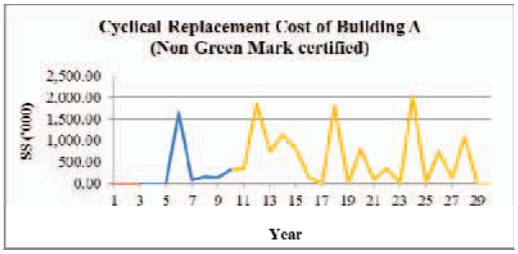


Figure 4 Cyclical replacement cost of Building A

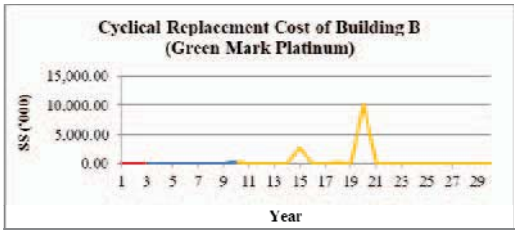


Figure 5 Cyclical replacement cost of Building B

As seen from Figure 6, there is a total life cycle cost savings of $10.2 million through the 30-year cycle for Building B, with an annual LCC savings of about S$340,000. It shows that in the long run, owners/developers of Green Mark buildings can save substantial amount of cost, hence justifying the initial higher construction costs incurred due to the green mark installations.

However, it has to be noted that the cyclical replacement cost information in *Figure 4* and *5* utilised physical life expectancy as the method used to identify the annual capital expenditure for cyclical replacement. The basis of estimate does not take into account specific design, position, local ground conditions or mis-use that may occur. Thus, the cost estimates plotted are indicative only and provided as an "order of magnitude cost allowance", without inclusion for maintenance and operational costs.

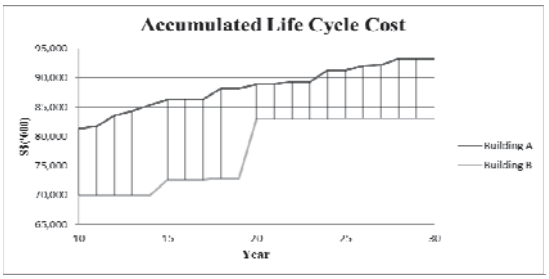


Figure 6 Accumulated life cycle cost

The next section discusses the utilization of RElifing® to assess and determine the suitability and feasibility of retrofitting to extend a building's life.

RElifing® application case study

RElifing®, the final cost engineering methodology, is an analytical and economical sustainability tool that all building owners should consider beforing carrying out A&A works. It is intended to provide a rapid and simple view of existing buildings to assist owners and facilities managers to decide whether it is worthwhile extending the life of the building (and if so, for how long), or whether disposal or replacement are better options. This study should be concluded before making criticial decisions on A&A and redevelopments. RElifing® also aims to extend the life of a building (thereby maximizing its value) by utilizing minimal resources – an integral instance of sustainability. If the study concludes that it is viable to extend, the eventual A&A works would include other works to upgrade the building, such as meeting the current codes like the Green Mark requirements.

This case study applied with RElifing® involved a sports complex which comprises of 4 segments – the main stadium, two annex blocks and a multi-sports hall. The complex was constructed in several phases – the Main Stadium built in the 1930s, the 1st Annex Block in the 1950s, the 2nd Annex Block and the Multi-Sports Hall in the 1990s.

Based on a detailed survey of the building's major components and a comprehensive review of available documentation, the intrinsic value of the main stadium (i.e. the cost of constructing the building new as of the reported date) is approximately $30 million. By assigning reasonable life cycle years against various building components and weighting them proportionate to the total cost of the building, the weighted average service life (WASL) of this building upon its initial construction was 70 years.

It was found that the Main Stadium has a remaining intrinsic value of approximately $2 million, or 8% of its full intrinsic value. The remaining WASL is calculated as a little over 5 years, indicating that the Main Stadium has lasted well beyond its expected life and has virtually no tangible value (or life) left ,as illustrated in *Figure 7*.

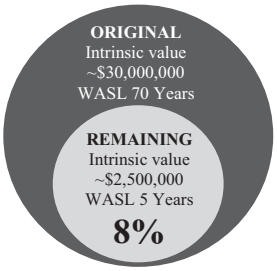


Figure 7 Original and remaining intrinsic value for Main Stadium

Various building components that required repair or replacement in order to continue utilizing the building for a timeframe of additional 5, 10 or 25 years were identified. The cost for these repairs is shown in *Figure 8*. The study indicated that each of the options for extending the life of the Main Stadium by 5, 10 or 25 years is uneconomical compared to replacement as the building is close to the end of its useful life. Hence, from an economical standpoint, replacement is recommended.

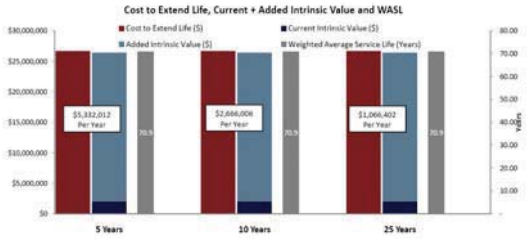


Figure 8 Cost of repairs to further utilise 1st Annex Block for 5, 10 and 15 years (extending its life)

The 1st Annex Block had a remaining intrinsic value of $20 million (25% of its full intrinsic value). The full WASL of the building is calculated as 65 years of which 16 years remained at the time of RElifing® assessment. This indicates that the 1st Annex Block lasts slightly better than typical buildings of the same purpose and has only a small percentage of its value and WASL left. *Figure 9* indicates that the cost to extend the 1st Annex block for a further 5 to 10 years is expensive and would cost between $24 million to $27 million, with only marginal increase in the remaining intrinsic value. The cost to extend its life for 25 years would cost between $55 million to $60 million, but would provide little or almost no improvement. Therefore, considerations should be given to replace it.



Figure 9 Cost of repairs to further utilise 1st Annex Block for 5, 10 and 15 years (extending its life)

The 2nd Annex Block was found to have an intrinsic value of $57 million, or 65% of its full intrinsic value. The findings showed that this segment has a significant percentage of both its value and life remaining (42 years WASL left). This segment has reached a stage of its life where even a modest life extension of 5 years will incur significant cost due to the amount of components that have already reached the end of their original life, as shown in *Figure 10*. Therefore, it is more cost effective to extend its life by 25 years.

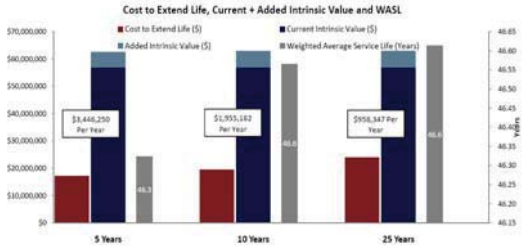


Figure 10 Cost of repairs to further utilise 2nd Annex Block for 5, 10 and 15 years (extending its life)

The remaining intrinsic value is $12 million of its full intrinsic value. Findings also showed that this segment has a significant percentage of intrinsic value (67%) and WASL (42 years) left, as shown in *Figure 11*.

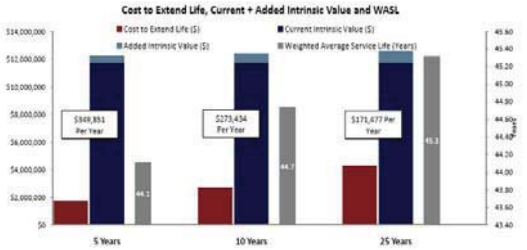


Figure 11 Cost of repairs to further utilise Multi-sports Hall for 5, 10 and 15 years (extending its life)

This case study of RElifing® application demonstrates the capability of cost engineering tools to identify the present cost of the building and its remaining lifespan, proritise capital improvement spending, identify areas to allocate resource for effective results and support decisions on whether to maintain, upgrade or replace. In addition, the maximisation of existing resources' life acts as a sustainability measure as well.

CONCLUSION & LIMITATIONS

The present study proposed a schematic flow for LCC-oriented cost management of buildings, discussed various cost engineer methodologies and also identified trends via case studies. However, the results are constrained by the limited sample size of

projects and suffered from the unavailability of more in-depth information, of which deeper study and analysis could have been conducted.

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DESIGN TOOLS FOR LIFE CYCLE ANALYSIS AND DURABILITY EVALUATION OF BUILDING SYSTEMS: A RESEARCH ON THE BUILDING ENVELOPE

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ABSTRACT

The behavior and service life prediction of building systems requires to develop tools to assist the designer. The paper is focused on a research carried out in the Department of Architecture and Design with the Department of Mathematical Sciences of the Politecnico di Torino. The goal is to develop a design tool to forecast the building subsystem durability and to help the designer in design options. The method is based on FMEA (Failure Mode and Effect Analysis) developed in a qualitative way as well as in a probabilistic way. The analyst assess the functional models, the failures and the consequent predicted service life of components. The designer will select materials defining the risk coming from environmental agents, design, materials and workmanship. The estimated service life has been assessed by Monte Carlo method. The external walls was the example tested using data by investigations in the area of northern Italy and from literature.

INTRODUCTION

The durability of materials and components is not usually well defined at the design stage. Many times the knowledge of the behavior of the building subsystem in the real use is not available to the designer unless well known by experts. Codes of practice, technical literature on building pathology and durability are not so widespread and easy to find by designers.

The consequence of this lack of information is an overwhelming amount of building failures, damages, maintenance expenses and environmental costs.

The life cycle oriented design requires an accurate forecasting of the durability and conscious design options. Technical solutions and assemblies, products and materials have to be tailored for the specific project, site and environmental agents.

The goal of the research is to give to designers a simple but powerful design tool to evaluate a specific design of a building subsystem (e.g. an external wall) in face of durability and maintenance in a particular circumstance. This design tool shall not give an ultimate evaluation but help the designer in the choice. The factors affecting durability are not simply the materials and products adopted but also the form of the building, the environmental agents (i.e. the climate) and the workmanship skills of the construction firms involved. These factors are different from a site to another, from a project to another and must be evaluated in every specific site and project.

The building subsystem configurations can be easily referred to specific types. In this way could be reasonable to study the behavior and the service life of a defined range of subsystem solutions and save the related data. The library of solutions can be associated with BIM software to optimize the options in regard to materials, products and components durability, reuse capability and performances.

The main objective of the method proposed is to avoid errors in design, construction on site, maintenance. Moreover, the optimization of durability of the system and of the components will allow a reduction of the environmental costs and effects.

THE FMEA IN THE BUILDING DOMAIN

The durability assessment methods are stated by the ISO 15686-2011 *"Buildings and Constructed assets – Service Life Planning–part 1: General Principles"*. Among them the Failure Modes and Effects Analysis (FMEA) is highlighted as a promising method to assess service life and durability. This tool, developed in the electronic as well as in nuclear field, has been proposed in the building domain since the past decade (Talon A., 2005;Pollo R., 2006). Many efforts have been made to build up a quantitative method based on FMEA but the goal seems still unreached and the methodologies proposed appear still on test.

The FMEA allows to easily identify in a quite complete manner, failures their causes and consequences. This feature pushed the use of this method above all in a qualitative way. Such a tool is commonly used to evaluate and improve design of industrial plants as well as services management.

The advantage of using FMEA methods are the systematic review of relationship between cause and consequences but it requires a long time to be developed and advanced skills and knowledge are required.

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But, as the researchers know, the modeling of the behavior of a building system in use is fairly difficult. Many are the agents involved and also the functions of the components are not easily defined. Moreover, the building products aren't in many cases certified, and their quality is not well controlled and steady. Anyway, we assume that the quality improvement of the building process towards sustainability will assure a more and more control on materials and products. (i.e. with environmental certifications like EPD).
The FMEA can help to assess the durability of the building subsystems and components and to improve the subsystem design environmental balance. The design options can be optimized improving durability, and consequently reducing energy consumption and emissions, and allowing reuse of the components. This process can be summarized in Figure 1, where the continuous lines are the steps of the process and the dotted are the feedback on the design.

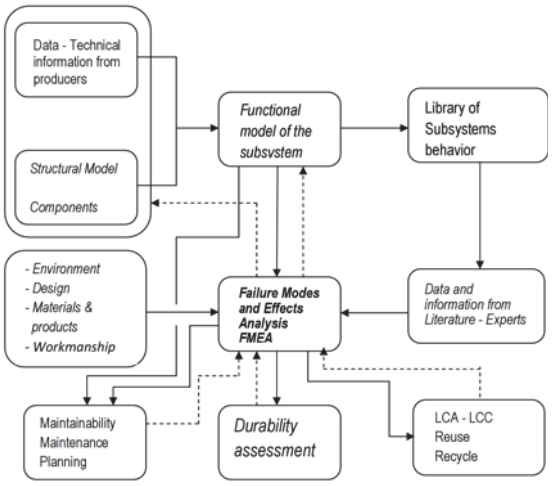


Figure 1 Process of durability analysis

DEVELOPMENT OF THE MODEL

Different building projects are in most cases differently stressed by the environmental agents and users. Moreover, materials used can have specific performances and the workmanship skills can influence the expected service life of the component and of the system. Similarly, the design faults can have severe consequences on the service life. In the analysis we have to consider and evaluate all these factors.
The goal is to allow the designer to analyze, and eventually to compare, design options and materials in a particular environment and with defined skills of the construction firms involved. This situation is quite usual in professional practice but such an analysis is fairly difficult and time consuming.
Thus you need to know how these different elements, like environmental agents, design, material, workmanship affect quality and service life. The designers usually know such information but sometimes dont have a complete knowledge of the behavior of the building subsystem, could be a roof or a pavement or an external wall. Therefore this knowledge is easily accessible on technical literature and codes of practice or can be obtained by the experts.
Moreover the data coming from existing knowledge on the behavior of building systems and materials must be expressed in a feasible way to allow for a quantitative evaluation.
The more simple way to do that is to associate an estimated service life to every cause of failure considering its probability of occurrence. Such a probability will depend on the assessment of the factors of the specific project by the designer. Indeed the designer is usually aware of the specified constraints of the project.
The expected service life due to the failures will be evaluated by the experts and will be a part of the model, considering the effects of causes alone and combined.
The development of this step of the study requires to define a structural and functional model to simulate the service life of subsystems. (Talon A., 2005)
The steps in the process of analysis developed are:
-structural model, requiring the definition of the parts, their links, the environment and use;
-functional model, including the functions identification for each component and for the building product;
-Failure Modes and Effects Analysis, taking account of failures and their consequences on the functionality of the system, of seriousness of the failure and of causes depending on their origin (material performances, environmental agents, workmanship skill);
-Graph of relationship between components based on FMEA results;
-Probabilistic calculation of the expected service life by Monte Carlo method.
The functional model identifies a design solution that can be assumed like a model with a specific behavior in its service life (i.e. a ventilated facade). The specific materials used and their performances will be defined in the specific project and by the designer. According to their characteristics they will comply with their role in a good or in a bad way facing different environments and with a specific design life.
The analysis must be carried out for each function separately (i.e. water tightness, air tightness, heat transfer control, vapour transfer control, etc.).
In the proposed model the FMEA must be carried out by the analyst for the definition of failures, causes and effects on expected service life. The designer, the user of the tool, must evaluate, on a scale of severity, the factors affecting the probability that the failures occur.

The failure probability calculations of the subsystem due by a single cause (identified by the letter T) or by an additive effect (identified by letter S) will be processed by the system.
In this way the input of the model by the designer-user are only the probability estimates of the risk of occurrence of failure coming from:
-design factors;
-materials performance levels;
-environmental agents (more or less severe);
-workmanship skills level.
The scale of severity must be defined by the analyst who defines also the expected service life coming from the specific cause.
In the study is analyzed a simple external wall made by a support masonry layer, a cement render and an acrylic painting (Figure 2).

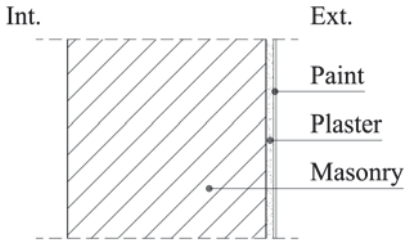


Figure 2 External wall scheme

Data on pathologies and failures of this kind of building subsystem are available in the literature. The reference service life is also defined in a number of publications. (Perret J., 1995) The input data by the designer has been supposed by the authors.
The function investigated is the water tightness of the layers.
A description of the model was made by making use of a specific example and a probability evaluation has been developed.
The model is based on the assumption that different independent competing risks, corresponding to different causes of failure, can reduce the reference service life of a component. The risks are in competition, in the sense that the effective service life corresponds to the occurrence of the first one of the failures, or to the reference service life whenever no failures occur. Different causes of damage can be considered, different components can enter in the models, and the degradation of a component can be one of the possible causes of failure for another one.
Thus, the effective service life of a component is defined as the minimum between independent failure times, each one with its probability of occurrence.
The graphical representation of the model has the purpose to let immediately understand what are the possible causes of failure for each component, what are the components involved in the degradation system, and what are the relationships between components. The basic blocks of the graph describing the system are the nodes, each one corresponding to the service life of a component or the time for a specific failure, and the arrows. Two kind of nodes are considered: round up ones, representing the effective service life of components, and square ones, representing the different causes of failure. Also, two kinds of arrows are admissible: plain arrows entering in round up nodes, describing the competing risks causing the failure of the component, and dashed arrows, entering in square nodes, describing the fact that the specific cause time to failure starts at the occurrence of a component. In the figure 3 is shown the relationship between each component, the round up nodes, of the subsystem, with his estimated service life, with each other.

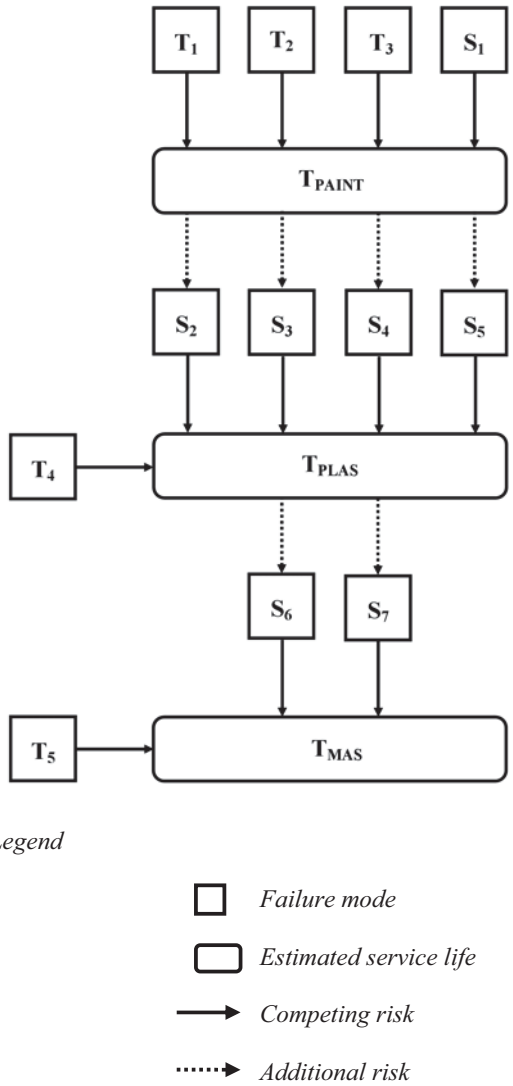


Figure 3 Graph of water penetration phenomena through the wall

Every plain arrow entering in a round up node represents one of the competing causes of failure of the component, and to every plain arrow is associated

a string of real values describing the probability of occurrence of the failure and its seriousness in the service life. Arrows can be directed from a component to another, in case that the failure of the first component immediately cause the failure of the second one. On the contrary, the dashed arrows are used to describe the fact that, whenever a component has a failure, a new effect of degradation starts for another component, through a specific competing risk.

Thus, dashed arrows move from component's lifetimes (inside round up nodes) to risks (square nodes).

For every functional system, the model is defined and designed by the analyst, who should consider and represent all possible relationships between components and all possible degradations and the corresponding severities. The string of values describing the probabilities of occurrences of specific failures, are compiled by the user, who assign them considering environmental conditions, characteristic of materials and quality of workmanship.

The string of values associated to each plain arrow (say, e.g., arrow *i*, corresponding to the specific failure time *Ti*) contains the information on the possible failure that follows.

- *si* (seriousness), that is the effective service life in presence of the specific cause of degradation
- *pi* (probability of design fault), that is the probability that the specific cause of failure occurs in the design of the system. In most of the cases they are assigned equal to 0, when environment or available material ensure that the specific cause of failure can nor occur, or they can be equal 1 in the opposite case. Values between 0 and 1 can be also assigned. Moreover, more than one probability of design fault can be assigned to an arrow (if more concomitant design errors should occur to generate the specific degradation)
- *qi* (probability of workmanship mistake), that is the probability that an erroneous technical mistake is made in the physical realization of the component. High values of *qi* are assigned by the user whenever it is sure of a poor workmanship quality.

The probability of the occurrence of failure *i*, at the time *Ti* described by seriousness *si*, is given by *pi* if it depends only on design faults, or is given by *qi* if it depends on workmanship mistakes, or on their product if both design faults and workmanship mistake should occur.

Two possible kinds of risks are admitted by the model: major failures, due to the action of severe external agents or to serious design and assembly errors having times denoted by *Ti*, and failures due to the contemporary non independent causes of physical slow degradation, having times denoted by *Sj*. As for the other risks, they act in competition to define the service life of the component, and become the effective service life if the corresponding degradation reach a fixed threshold before the other risks. As for risks of the first kind, more than one risk of this second kind can enter a round up node, and they have their own seriousness index. The difference is that times *Sj* can also depend on failures of some of the components, and that it corresponds a pair of probabilities *pj* and *qj* defined as above for each one of the degradation causes that should occur simultaneously.

Considering the system represented in Figure 3, an example of possible strings of values associated to the arrows is given in table 1. This values are defined by the user, who knows the specific environmental and design conditions of the system.

For example, the table provides the following data regarding the component "External painting". Its reference service time is 10 (years), and the competing risks $T1$, $T2$, $T3$ and $S1$ (corresponding to "Meteoric washout", "Not suitable weather conditions during the assembly", "Not transpiring painting" and a set of slow degradation factors) can reduce it. The failure time $T1$ due to "Meteoric washout" is set to be 6 years according to the seriousness, and it occurs if both design fault and careless construction occur. All these data about the mentioned failure modes are coming from the FMEA developed for the example.

The probability of design fault $p1$ is the product of the probabilities of failures due to forms, material and environments (0.43 in the example), and the probability $q1$ of workmanship mistake has been set equal to 0.2, so that the probability of occurrence of this risk is the product $p1 \cdot q1 = 0.0128$. Thus, $T1$ is a random life that is equal to the reference service time (10 years) with probability 1-0.0128=0.9872, or equal to 6 with probability 0.0128. The random time $S1$, describing the time for which the slow degradation due to "Air pollution", "Meteoric washout" and "Not suitable weather conditions during the assembly" reach a fixed threshold, is such that it will be equal to the seriousness 5 if all the three factors occur simultaneously, thus with probability $0.8 \cdot 04 \cdot 0.4 \cdot 0.2 = 0.0256$, and equal to the reference service time 10 with probability $1 - 0.0256 = 0.9744$.

The effective service time of the external painting will be thus the random time *Tpaint* defined as $Tpaint = \min\{T1; T2; T3; S1\}$. Being a random time, it is described by the list of possible values it can assume, each one with its corresponding probability. These values and the corresponding probabilities can be calculated analytically, through probability calculus, or by using Monte Carlo methods, i.e., generating a set of simulations of the whole system, and using them to estimate possible values and corresponding probabilities.

The values and the corresponding probabilities obtained using a Monte Carlo procedure (with 5000 simulations) for the specific *pi* and *qi* in the example are given in table 1.

The random life *Tpaint* can now be included in the computation of the random effective life of the

plaster, *Tplas*, which is defined as *Tplas* = min{*T*4; *S*2; *S*3; *S*4; *S*5}. In fact, the risks *S*2; *S*3; *S*4 and *S*5 depend on *Tpaint*, in the sense that the corresponding degradations start at the occurrence of *Tpaint*. Thus, the behaviors of *Tplas* and *Tmas* also can be estimated through a Monte Carlo procedure, simulating realizations of all failure times according to the probabilities and severities given by the user. For our example, the resulting values and probabilities are 4 provided in table 1.

The table also contains some short descriptors of these random times, e.g., their means, medians and percentiles corresponding to 10%. It should be observed that maintenance of components is not included in this simulation. It can be also included, appropriately acting on the dashed arrows (by delaying failure times in case of maintenance of the component). The resulting values and the corresponding probabilities for *Tmas* in this case, again obtained through a Monte Carlo procedure, are given in table 2.

Table 1
Mean value of Predicted Service Life for Paint, Plaster and Masonry, without any maintenance

T_{PAINT}		
Years [n]	Cases [n]	Percentage value [%]
5	113	2,26
6	224	4,48
7	3726	74,53
10	936	18,72
TOT	4999	100,00
Mean value = 7,47		
Median value = 7		
10° perc. = 7		

T_{PLAS}		
Years [n]	Cases [n]	Percentage value [%]
12	15	0,30
13	34	0,68
14	480	9,60
17	127	2,54
20	646	12,92
30	3697	73,95
TOT	4999	100,00
Mean value = 26,67		
Median value = 30		
10° perc. = 14		

T_{MAS}		
Years [n]	Cases [n]	Percentage value [%]
5	471	9,42
14	1	0,02
15	9	0,18
16	108	2,16
19	16	0,32
22	108	2,16
32	615	12,30
60	3671	73,43
TOT	4999	100,00
Mean value = 49,38		
Median value = 60		
10° perc. = 16		

Table 2
Mean value of Predicted Service Life for Masonry, with maintenance

T_{MAS}		
Years [n]	Cases [n]	Percentage value [%]
5	508	10,17
24	3	0,06
27	6	0,12
30	86	1,72
60	4391	87,93
TOT	4994	100,00
Mean value = 53,83		
Median value = 60		
10° perc. = 5		

CONCLUSION

In this paper we suggest a methodology to assess in a relatively simple way the expected service life of building subsystems, as external walls taking account of specific design and form of the building, environmental conditions, materials as well as workmanship level. The model allows the designer to forecast consequences of design options using information and knowledge in the built up procedure by a panel of experts. Such a procedure must be set up by the FMEA analyst on the base of information by codes of practice, literature, products information sheets and expertise.

In this way a database of analysis referred to specific types of subsystems could be put together and adjusted by the experience. Such an experience will be a part of a library of tested solutions by the design firm or by the facility manager. Organisations managing broad estates can be interested to implement this kind of method to improve quality of buildings.

The research requires to be carried out to test the procedure on a range of different building subsystems with specific structural and functional models. The

increase of complexity of subsystem to be investigated will be the challenge for the development of the research.
The results from simulation have given very reasonable results according to the practitioner experience and to the literature. In any case the model must be implemented and tested on a number of real cases.

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PERFORMANCE-BASED ASSESSMENT OF DAYLIGHT ON TROPICAL BUILDINGS- A CASE STUDY

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ABSTRACT

The utilization of daylight can significantly affect building performance, energy efficiency, productivity, as well as occupants' comfort and satisfaction in buildings. This paper aims to assess daylight performance metrics for tropical office buildings. We first evaluated an array of daylight performance metrics, namely daylight factor, daylight autonomy, continuous daylight autonomy, daylight autonomy max, and useful daylight illuminance. Subsequently, a systematic approach toward assessing daylight performance is presented. The approach is exemplified using the case study of two selected offices in CREATE Tower, an air-conditioned office building located in Singapore. Thereby, a set of variants was generated based on four investigated configurations and then compared. This study contributed to the assessment of the daylight performance and prediction of the consequences of retrofitting alternatives toward fostering the utilization of daylight in existing buildings in the tropics. Furthermore, the outcomes of this effort are expected to serve as a solid basis towards a simulation-based daylight responsive building systems control demonstration in lighting and shading domain.

INTRODUCTION

Lighting accounts for 20% of energy use in Singapore's office buildings, making it one of the primary energy loads in the building sector, and a critical factor in design strategy for effectively improving office building energy efficiency. To achieve a higher level of energy efficiency and sustainability in the buildings sector, the consideration of natural daylight utilization during the daytime is crucial. Towards this end, the electric lighting would then be supplemental, such that significant reduction of electric lighting demands can be achieved. That can result in significant impacts on building performance, energy efficiency, productivity, as well as occupants' comfort and satisfaction. Nowadays, the most used daylight metric is based on simplified daylight performance model at one time step under the standardized overcast sky. There have been concerns that the results obtained from such metric may not reflect intermediate daylight performance conditions over an extended period of time with variable sky conditions. In recent years, a number of more elaborate daylight metrics have been proposed (Reinhart et al. 2006; Cantin and Dubois 2011; DiLaura 2011). In this context, the research effort describes a systematic approach toward obtaining and assessing simulation-based daylight performance data from high-rise office buildings.

This approach is currently being applied within the framework of a living lab project, with the support of the Singapore-Berkeley Building Efficiency and Sustainability in the Tropics (SinBerBEST) Program. Thereby, amongst other activities, local climate and building performance (involving visual/ thermal performance and occupancy) data are being collected for this selected living lab in CREATE Tower, a high-rise office building in Singapore. The high-level goal of this living lab research effort is a comprehensive understanding of visual performance in tropical built environment, including the utilization of daylight, energy efficiency, occupant comfort, and integrated intelligent lighting and shading controls.

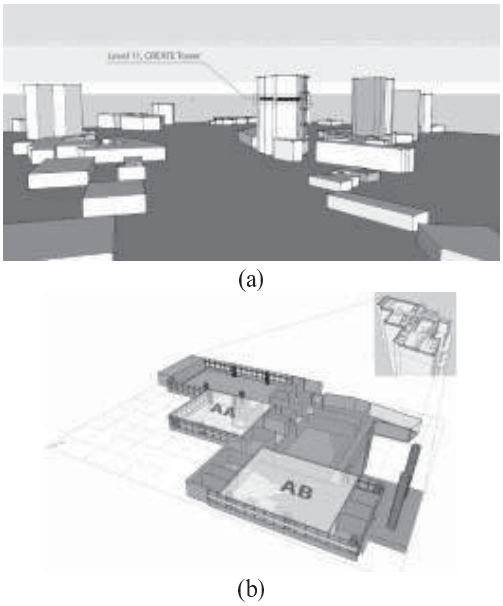
This paper presents a preliminary assessment of five daylight performance metrics for tropical office buildings. We first evaluated an array of current daylight performance metrics. Thereby, both static (daylight factor) and dynamic (daylight autonomy, continuous daylight autonomy, daylight autonomy max, useful daylight illuminance) daylight performance metrics are considered. Subsequently, a systematic approach toward assessing daylight performance based on above-mentioned metrics is presented. The approach is exemplified using two selected offices (Area A and B) in CREATE Tower, an existing air-conditioned office building located in Singapore. This study contributed to the assessment of the daylight performance and prediction of the consequences of retrofitting alternatives toward fostering the utilization of daylight in existing buildings in tropics. Furthermore, the outcomes of this effort are expected to serve as a solid basis towards a simulation-based daylight-responsive building systems control and demonstration in lighting and shading domain.

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APPROACH

Description of the case study model

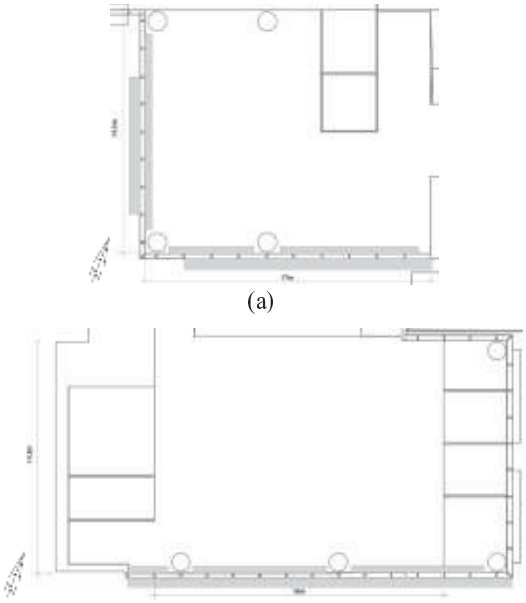
Daylight performance simulation was conducted for two offices (Area A and B) at level 11 in CREATE Tower, University Town, Singapore (see Figure 1and 2). To present the performance study in a structured manner, we use the following notations: "AA" denotes Area A, and "AB" denotes Area B. High ceiling is specified with code "H", whereas low ceiling is specified with code "L". In addition, we refer to the unshaded windows henceforth as "1" and the shaded windows (adorned with exterior/interior shelves) as "2" respectively. For each area, four different configurations were then evaluated (i.e., H1, H2, L1, L2, as per Figure 3). Thus, eight variants (AAH1, AAH2, AAL1, AAL2, ABH1, ABH2, ABL1, ABL2) were considered. The information regarding office geometry, building materials, and optical properties of the surfaces for daylight simulation are listed in Table 1. The whole variants together with the surrounding urban context were modelled using Google SketchUp and exported to Ecotect and DAYSIM for further daylighting analysis. Also, a set of illuminance sensor points was deployed in AA and AB based on a grid resolution of 1m x 1m at work plane height (0.8m above the floor). Thereby, the electric luminaires turned off were considered. However, as the base case study, no shading devices were assumed at current stage. The requirements (involving properties) and effects of the shading devices and interior furniture will be studied in the future stage.



(a)

(b)

Figure 1 (a) Site and the surrounding urban context; (b) perspective of AA and AB at CREATE Tower



(a)

(b)

Figure 2 Plan views of AA (a) and AB (b) together with the positions of the exterior and interior shelves.

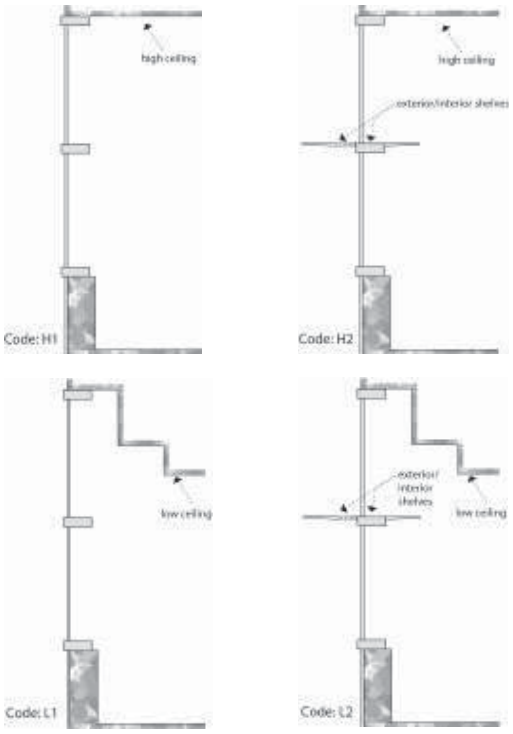


Figure 3 Illustration of four investigated configurations, namely H1, H2, L1, L2

Table 1 Building materials and optical properties

Area Code	AA	AB
Width (m)	17	18
Depth (m)	14.5	14.5
Height (m)	3.72 (high ceiling)/ 2.82 (low ceiling) for both areas	
Window sill height (m)	0.875 for all windows	
Glazing Tvis	0.61 for all windows	
Exterior & interior shelves (m)	0.6 & 0.4 for both areas	
Reflectance of shelf surface	0.8 for both areas	
Reflectance of ceiling surface	0.7 for both areas	
Reflectance of wall surface	0.6 for both areas	
Reflectance of floor surface	0.4 for both areas	
Reflectance of ground	0.2	

Weather File

The weather file used was Singapore (latitude 1.22°N, longtitute 103.59°E), with the ASHRAE International Weather for Energy Calculations (IWEC) data for Singapore, WMO 486980 downloaded from EnergyPlus weather data website (DOE 2013a). The IWEC weather files for Singapore are derived from up to 18 years (1982-1999) of 8760 hourly weather data originally archived at the National Climatic Data Centre. The weather data is supplemented by solar radiations and illuminance estimated on an hourly basis from earth-sun geometry and hourly weather elements (e.g. cloud coverage) (DOE 2013b).

Computational Simulation Tools

This study was entirely carried out by simulation using the Autodesk Ecotect Analysis (Autodesk 2013), and DAYSIM (Reinhart and Breton 2009; Reinhart et al. 2013). DAYSIM is a RADIANCE-based day-lighting analysis tool developed by the National Research Council of Canada and the Fraunhofer Institute for Solar Energy Systems in Germany. DAYSIM employs the daylight coefficient method (Trezenga and Loe 1998) to efficiently calculate illuminance distributions under all sky conditions in a year and the Perez sky model (Perez et al. 1993). The simulations were performed assuming that these two selected offices (i.e., AA and AB) were occupied Monday through Friday from 9:00 to 17:00. The occupant leaves the office three times during the day (30 minutes in the morning, 1 hour at midday, and 30 minutes in the afternoon). The occupant performs a task that requires a minimum illuminance level of 500 lx (SS 2013). For all simulations, ambient parameters in Radiance are set as shown in Table 2.

Table 2 Radiance ambient parameters

Parameter	Description	Value
-ab	Ambient bounces	5
-aa	Ambient accuracy	0.1
-ar	Ambient resolution	300
-ad	Ambient divisions	1000
-as	Ambient super-Samples	20

Performance Metrics For Daylighting

To conduct the daylight performance analysis for AA and AB, we propose a set of evaluative metrics, whereby both static (daylight factor) and dynamic (daylight autonomy, continuous daylight autonomy, daylight autonomy max, and useful daylight illuminance) are considered (see Table 3). Daylight factor for static simulation is calculated at single point in time, while dynamic metrics are calculated based on an extended period of time with variable sky conditions on an annual basis. Thus, dynamic metrics could provide more valuable detailed information on daylight performance (DiLaura 2011).

i) Daylight Factor (DF): Daylight factor (DF) is the most widely conducted metric for daylight performance in buildings (DiLaura 2011). A daylight factor is the ratio of internal light level at one point in a building to the unshaded external light level under the Standard CIE overcast Sky (Trezenga and Loe 1998; Pollock 2009; Cantin and Dubois 2011). Daylight factor is static simulation (i.e. at one time step) and used in architecture and building design for assessing the internal daylight availability as perceived on the working plane or surface based on the occupants' work activities.

ii) Daylight Autonomy (DA): Daylight autonomy (DA) is the simplest and most widely conducted annual metric. It is generally defined as the percentage of the occupied period (hours) of the year that the minimum daylight requirement is exceeded through the year. Such metric as DA could be employed to evaluate performance at individual points and address the spatial daylight distribution (Reinhart 2006; DiLaura 2011). The main advantage of daylight autonomy over the daylight factor is that it takes facade orientation and user occupancy profiles into account and considers all possible sky conditions throughout the year (Reinhart 2002).

iii) Continuous daylight autonomy (DAcon): In addition to daylight autonomy, a modified metric "continuous daylight autonomy" (DAcon) proposed by Rogers attributes partial credit to time steps when daylight illuminance lies below the minimum illuminance level (Rogers 2006). For example, in the case where 500 lx is required and 300 lx of daylight is received at a given time step, a partial credit of 300 lx/500 lx=0.6 is attributed for that time step. Thus, the metric acknowledges that even a partial contribution of daylight to illuminate a space is still beneficial.

iv) Daylight autonomy max (DAmax): To simultaneously consider the potential appearance of glare, Rogers (2006) also proposed a second indicator called daylight autonomy maximum (DAmax). DAmax compiles the percentage of times during a year when the illuminance at a sensor is at least 10 times the recommended illuminance. For instance, for an office space with a design illuminance of 500 lx DAmax corresponds to 5000 lx (Reinhart 2006). In such a situation, there is a high chance that this will correspond to a situation with a direct sunlight patch at the sensor and hence glare (Dubois and Flodberg 2013).

v) Useful daylight illuminance (UDI): Useful Daylight Illuminance (UDI) is another modified version of Daylight Autonomy (Nabil and Mardaljevic 2005a; Nabil and Mardaljevic 2005b). This metric complies the number of operating hours based upon three illuminance ranges, namely 0-100 lx, 100-2000 lx, and greater than 2000 lx. Useful daylight is considered to occur when the daylight illuminance fall into the range of 100 lx and 2000 lx (UDI100-2000) (DiLaura 2011). Thus, it provides full credit only to values between 100 lx and 2,000 lx suggesting that horizontal illumination values outside of this range are not useful.

RESULTS

A study of daylighting performance for AA and AB using a set of simulation tools (i.e. Ecotect and DAYSIM) was carried out and generated an extensive quantity of data. The data was analyzed, some of which are presented in below.

Table 4 shows the simulation results of eight specified variants (i.e., AAH1, AAH2, AAL1, AAL2, ABH1, ABH2, ABL1, ABL2) in accordance with the previously described daylight performance metrics, namely daylight factor (DF), daylight autonomy (DA), Continuous daylight autonomy (DA_{con}), Daylight autonomy max (DA_{max}), and Useful daylight illuminance (UDI). Note that the simulation results were calculated based on the mean values. To provide a series of dynamic daylight performance analysis for these eight variants, such metrics as DA_{con} (see Figure 4), DA_{max} (see Figure 5), and UDI (see Figure 6) were conducted respectively. Figure 4 depicts the DA_{con} with 500 lx specified as the DA threshold (DA_{con500}) and the percentage of the space exceeded 500 lx over 40%, 60%, and 80% of the time on an annual basis. Figure 5 shows the percentage of the space exceeded 10 times the illuminance threshold (500 lx) over 5% of the time on an annual basis. In an effort to compare the UDI metric in these eight variants based on the UDI criteria (illuminance range: less than100 lx, in the range of 100 and 2000 lx, and greater than 2000 lx) is presented in Figure 6.

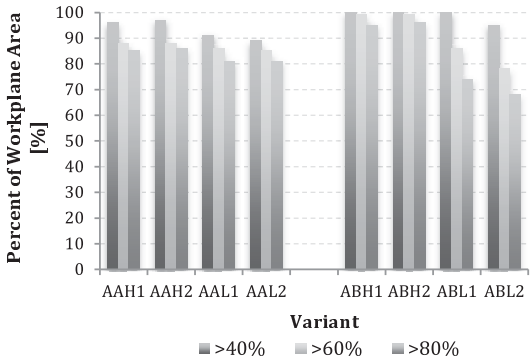


Figure 4 The percentage of workplane area above 40%, 60%, and 80% DAcon (500 lx)

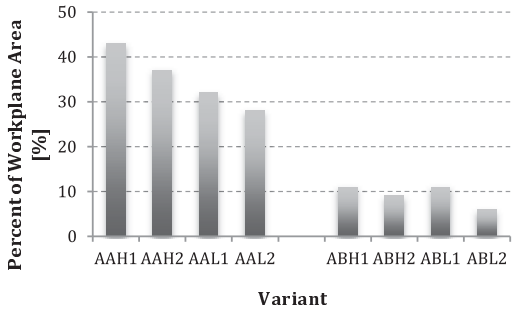


Figure 5 Percentage of workplane area above 5% DAmax

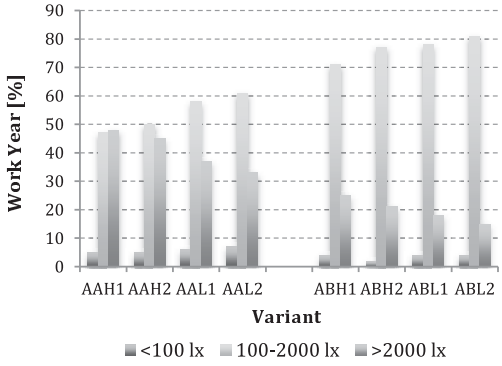


Figure 6 UDI (mean values, %) for eight variants, based on three illuminance range: less than100 lx, 100 lx to 2000 lx, and greater than 2000 lx

DISCUSSION

For the visual performance of each office space, one key point is how the occupants use the space (involving user requirements) and how we introduce daylight in an effective and appropriate manner. Such office spaces that are continually occupied for long-term periods of time and where daylighting would increase the productivity and even the energy efficiency of the space should be a high daylighting priority. Also, the provision of visual comfort (pertaining to low glare and good uniformity of daylight level) is critical. The simulation results support a number of initial conclusions, as discussed in the following two sections, namely daylight quantity and quality.

Daylight Quantity

The simulation results show that whole variants offer predominantly daylight appearances that can provide sufficient ambient lighting for the majority of the year (see Table 4 and Figure 4). According to the DF metric, these eight variants meet the DF (2%-5%) criteria. Moreover, DA_{con} (>60%) reveals that these eight variants deliver high uniformity of daylight throughout the spaces with greater than 80% of the space obtaining continuous daylight autonomies over 60 percent. On the other hand, as DAcon (>60% and >80%) shown in Figure 4 imply, there are variants (particularly ABL1 and ABL2) with passive design elements (i.e. low ceiling and exterior/interior shelves), which, while increase in items, give relatively lower levels of daylight appearance.

Daylight Quality

The results clearly show that higher percentage of workplane area in AA receives direct sunlight than in AB (see Table 4, Figure 5, Figure 6). This difference may be attributable to the building layout design, that more direct sunlight may deeper penetrate into AA (from the fenestrated southwest and southeast oriented facades) than into AB (from the fenestrated southeast oriented facades). Thus, the variants in AA are with less useful daylight level and more prone to glare. Specifically, UDI (>2000 lx) of 48% and DAmax of 43% raise a warning flag for Variant AAH1, which has a significantly brighter daylight appearance than the other seven variants. This implies that, strong potentials of glare and discomfort issues may occur in such space together with overheating effects. On the other hand, the results (see Figure 5 and 6) appear to suggest that the passive design elements (pertaining to low ceiling height and exterior/interior shelves) may significantly block and/or redirect the direct sunlight and thus effectively increase the useful daylight levels for the occupants (particularly in AA). The results also demonstrate that the effect of exterior/interior shelves is significant and as important as the effect of low ceiling height. For example, according to the DAmax metric, AAL2 is superior to the three other AA variants followed by AAL1, AAH2, and AAH1 (see Figure 5). Also, UDI (100-2000 lx) and UDI (>2000 lx) indicate that AAL2 is superior to the worst Variant AAH1 with UDI (100-2000 lx) rising from 47% to 61% and UDI (>2000 lx) decreasing from 48% to 33% (see Table 4 and Figure 6). Conversely, the results express that, in terms of the variants of AB, low ceiling and exterior/interior shelves have relatively low impacts on the probability reduction for discomfort glare (see Table 4 and Figure 6).

CONCLUSION

We have obtained preliminary results which have illustrated a systematic approach toward formulating, analyzing, and simulating day-lighting performance for a high-rise building in Singapore. We demonstrated the process and the generation of a set of computational performance simulation models on the basis of documentation of the building (geometry, construction, systems, operation), occupancy, and external (weather) conditions. Further developments of this study are expected to facilitate a detailed and dynamic daylight performance model, whereby the manual/automated blinds, interior office furniture, and lighting energy usage data are considered. The calibrated models will be then applied to compare and evaluate retrofit and enhancement alternatives (involving building envelope components) in view of building integrity, visual, and energy performance. Furthermore, the outcomes of this effort are expected to serve as a solid basis towards a simulation-based daylight responsive building systems control in lighting and shading domain.

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Table 3 Metrics conducted to assess daylighting performance in the offices in Tropics

Metric	Criteria	Description	Reference
Daylight factor (DF)	<2%	Gloomy appearance with rare daylight. Electric lighting needed during daylight hours.	(Trezenga and Loe 1998; Pollock et al. 2009; Cantin and Dubois 2011)
	2%-5%	Predominant daylight appearance. Some supplementary electric lighting required.	
	>5%	Daytime electric lighting rarely needed. Thermal/glare issues may occur along with the high levels of daylight.	
Daylight autonomy (DA)	--	The percentage of the occupied period (hours) of the year that the minimum daylight requirement is exceeded through the year.	(Reinhart 2002; Reinhart et al. 2006; DiLaura 2011)
Continuous daylight autonomy (DAcon)	>80%	Excellent daylight designs	(Reinhart 2002; Rogers 2006)
	60-80%	Good daylight designs	
	40-60%	Adequate daylight designs	
Daylight autonomy max (DAmax)	>5%	Not acceptable. A high probability that this will lead to a situation with a direct sunlight patch and hence glare.	(Rogers 2006)
	<5%	Acceptable	
Useful daylight illuminance (UDI)	<100 lx	Gloomy room with insufficient daylight.	(Nabil and Mardaljevic 2005a; Nabil and Mardaljevic 2005b)
	100-2000 lx	The room is with useful daylight levels for the occupants	
	>2000 lx	The room is too bright and exceeds the upper threshold of the useful range. Higher levels glare or discomfort maybe delivered together with overheating issues.	

Table 4 Simulation results of eight variants

Code	AAH1	AAH2	AAL1	AAL2	ABH1	ABH2	ABL1	ABL2
Daylight Factor (DF)	5%	4%	4%	3%	4%	3%	3%	3%
Daylight Autonomy (DA)	81%	81%	75%	73%	84%	82%	64%	57%
Continuous daylight autonomy (DAcon) >40%	96%	97%	91%	89%	100%	100%	100%	95%
>60%	88%	88%	86%	85%	99%	99%	86%	78%
>80%	85%	86%	81%	81%	95%	96%	74%	68%
Daylight autonomy max (DAmax) >5%	43%	37%	32%	28%	11%	9%	11%	6%
Useful daylight illuminance (UDI) <100 lx	5%	5%	6%	7%	4%	2%	4%	4%
100-2000 lx	47%	50%	58%	61%	71%	77%	78%	81%
>2000 lx	48%	45%	37%	33%	25%	21%	18%	15%

CROSS LAMINATED TIMBER (CLT)

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ABSTRACT

Cross Laminated Timber (CLT) is manufactured by binding layers of timber at 90 degrees to produce a solid timber panel which can support heavy loads like the structural and non-structural components in buildings. CLT has been successfully used in Europe for over a decade and more recently parts of North America, but not as yet in Singapore and Asia.

Since 2005, awareness of CLT as a structural building material and sustainable alternative to reinforced concrete, structural steel and load bearing brick & block constructions has been established and demand in Europe has increased dramatically in the last 5 years. CLT is prefabricated in factories and assembled on-site, leading to productivity gains and time savings as well as embodied carbon benefits across its life cycle.

World leading and landmark CLT projects predominantly completed in the UK and Europe have led to the recently completed and world's tallest residential timber structure, the FORTÉ project in Melbourne, Australia, designed and built by Lend Lease. This has been achieved through a coordinated transfer of knowledge to the Australian market which has set a precedent for introductions to other new markets at a global level.

The FORTÉ project will be used in this presentation as a recently completed and relevant project to demonstrate the product and system capabilities of CLT as an innovation that would improve construction productivity significantly and bring a much needed paradigm shift to our building industry.

In Asia, Lend Lease is working towards introducing CLT, aligned with our vision "To Create the Best Places" for our community.

The introduction of CLT is timely given Singapore's long-term growth aspirations of creating a cost-effective, liveable, sustainable and resilient city and regional R&D showcase hub in Asia.

INTRODUCTION

CLT was first developed in the sawmills and wood product manufacturing facilities of Europe in the early 1990s. A number of Austrian and German companies were developing and testing proprietary approaches; culminating in Merk (now Metsä Wood) being the first to manufacture and bring to market cross-laminated timber.

In 1996, an industry and academic joint research programme was undertaken in Austria which resulted in the development of what we know CLT to be today. The large format, solid engineered, cross-laminated timber (CLT) panel production was pioneered by companies such as KLH Massivholz, who in 1999 were one of the first companies to open a CLT manufacturing facility in Europe.

By 2005 awareness of CLT as a structural building material and sustainable alternative to concrete and brick & block had been established and demand in Europe had increased dramatically which led to increased awareness of CLT at a global level.

To date, Lend Lease in Australia has spent over three years undertaking technical due diligence on CLT and exploring different business opportunities. The construction of Forté, 23 apartments at Victoria Harbour, Melbourne completed early this year is the first CLT building in Australia and the tallest in the world currently.

All of the floors, roofs and walls are load bearing CLT and is one of the most significant forms of innovation in construction technology that Australia has seen in many years.

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Figure 1 - Architectural Image of Forté

CHARACTERISTICS OF CLT

CLT consists of large format solid engineered timber panels that are typically up to 3m wide by up to 16m long. The panels are formed from individual timber spruce/fir boards sourced from sustainably managed forests that are stacked in perpendicular layers of 3, 5, 7 or more lamella layers which vary in thickness to create CLT panels with typical thickness from 80mm up to 300mm. The layers are stacked at right angles and glued under high pressure to form the final CLT panel. CLT is typically produced in Northern Europe, predominantly in Austria but also in Germany, Switzerland and Italy.

The timber boards that are used are typically cut from parts of the log that have a lower value due to warping, cupping and twist of the boards due to changes in moisture content. These are normally sideboards which are actually the strongest boards from the log. The resulting CLT panel is strong, stiff, dimensionally stable and has the potential to replace reinforced concrete and steel construction for walls, floors and roofs for any building type.

The polyurethane adhesive used in the finger jointing process and to bond the lamella layers is a solvent-free and formaldehyde-free adhesive, an environmentally friendly product with no risk of toxic emissions at any stage in the product's life cycle.

The manufacture of the CLT panels occurs in a factory in which panels are produced using the CAD drawings and are similar to concrete precast panels which include all door / window openings, service penetrations and rebate routing for services.

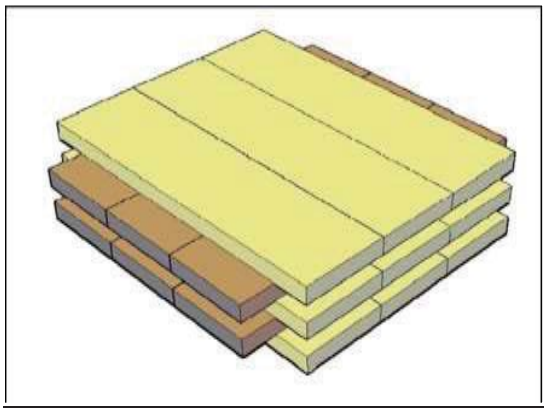


Figure 2 - Typical layering of a 5 layer CLT panel

MANUFACTURING PROCESS IN THE FACTORY

Kiln dried and sawn timber boards are graded and cross cut (to remove defects) then finger jointed and planed to form continuous boards which are then cross cut to the required length for either longitudinal or transverse layers. The cut boards are then laid up with the required number of cross layers (usually 3, 5, 7 or 11) with adhesive applied between each layer. The laid up panels are then pressed using a physical (hydraulic press) to create the final CLT mother (i.e. plain / uncut) panels which are then cut to create a bespoke child (i.e. custom cut) panel for the project.

Waste (saw dust, chippings and offcuts) from the finger jointing, planning, cross cutting, computer numerical control (CNC) and calibration processes are typically used as biomass to provide heat and power for the factory processes.



Figure 3 - Typical CLT manufacturing facility

METHOD OF ASSEMBLY ON-SITE

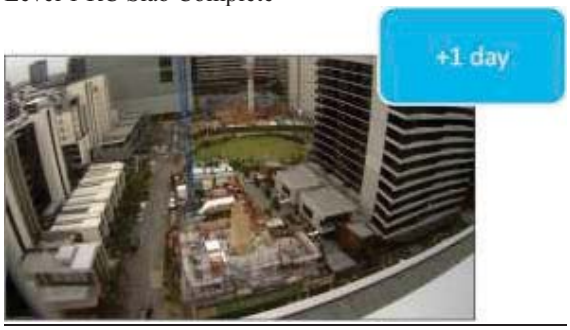
CLT child panels (i.e. custom cut panels) are typically lifted into final position directly from the delivery vehicle by mobile crane. CLT panels are

typically fixed to the sub structure and themselves using engineered timber wood screws and standard off-the-shelf pressed steel brackets.

The following photographic images show the speed of construction for the FORTÉ project in Melbourne, Australia, designed and built by Lend Lease:



Level 1 RC Slab Complete



First Panels Erected for Lift Core



Level 1 (Sequence 1) Walls & Pods



Level 2 (Sequence 1) Floor



Level 2 Floor Complete



Level 3 Floor Complete



Level 4 Floor Complete



Level 5 Floor Complete



Level 6 Floor Complete



Level 7 Floor Complete

Note: For time-lapse video of the full complete construction of Forte, please refer to this link *http://www.youtube.com/watch?v=QR8Z-5cyzrI*

MECHANICAL AND ELECTRICAL WORKS

All penetrations for services (i.e. mechanical, electrical and hydraulic) can be pre-cut into the CLT panels during the CNC process at the factory. This requires full coordination of the design (i.e. architectural, structural, mechanical & electrical including hydraulic) prior to fabrication drawings and manufacture.



LIFT SHAFT INSTALLATION

Set out below are photographic images of the CLT lift shaft installation process at Forte to further demonstrate the efficiency and productivity of using CLT:







BENEFITS OF USING CLT FOR CONSTRUCTION

Forté is built on the principle that what is good for the environment is good for the resident too. The use of timber is not only better for the environment, but also offers a strong, solid, warmer and more natural living experience. Timber reduces CO2 equivalent emissions by more than 1,400 tonnes when compared to concrete and steel, equivalent to removing 345 cars from our roads.

Key benefits of CLT include:

Safety:

- Reduced high risk work (e.g. work at heights). Elimination of injuries associated with formwork and reinforcing activities
- Reduced impact of construction and disruption to local communities
- Fewer operatives on site and for a reduced period of time.

Sustainable:

- Carbon neutral structural option – $1m^3$ of timber stores 0.25t of carbon
- Better thermal performance
- Generates zero waste
- Reduces fresh water consumption
- Enhances Indoor Environment Quality (IEQ)
- Reduces deliveries to site (up to 90% less truck movements was achieved for the Forte project).

Light Weight:

- 80% weight reduction as compared to concrete
- Less mass to support
- Reduces foundation requirement significantly
- Assist with poor ground conditions
- Basic craneage requirement on site.

Time Savings and Efficiencies:

- Reduced Preliminary & Supervision costs
- Savings in follow-on trades
- Reduced holding costs for developer
- High precision quality end product.

CONCLUSION

Choosing CLT construction rather than concrete and steel means that Forté will have positively affected the environment by:

- Reducing cumulative energy demand – non-renewable by 13 per cent
- Lowering eutrophication (the supply of excess nutrients to the water system) by 21 per cent
- Offering better thermal performance and requiring less energy to heat and cool. This means reduced energy and water costs with estimated average savings of $300 per year
- Reduction of waste on site and positive impact on the surrounding community (via reduced construction noise, truck movements and reduced concrete / general dust emission)
- Faster construction and less labour needed on site, compared to conventional construction methods
- Sustainability benefits throughout a building's lifecycle: timber has the lowest energy and water consumption of any building material and it is a renewable structural building material. Even at time of demolition, CLT is recyclable and can be reused.

The FORTÉ project (as the reference case study of this CLT paper submission) demonstrates the product and system capabilities of CLT as an innovation that would improve construction productivity significantly and bring a much needed paradigm shift to our building industry.

The introduction of CLT is timely given Singapore's long-term growth aspirations of creating a cost-effective, liveable, sustainable and resilient city and regional R&D showcase hub in Asia.

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1. Lend Lease Australia – Forte project case study (refer to website link: http://www.lendlease.com/en/australia/sustainability/~/link.aspx?_id=174B5553D8E34E05A55216CC6CA93E93&_z=z)

COLLABORATIVE ENGINEERING ASSISTANCE FOR A SUSTAINABLE DESIGN

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ABSTRACT

The paper discusses Virtual Design and Construction (VDC) decision environment, where key design and construction decisions that affect the sustainability features of the structure under consideration can be debated by the many stakeholders. AEC collaboration is fostered from pre-construction using Integrated Project Delivery (IPD) contract strategies. The environment proposed is one that fully utilizes the strengths of intelligent computer agents that bring required knowledge and information as the design solution is developing, interrogated and refined. In this way, many alternative design options can be rapidly explored that have an impact on such important areas as sustainability, safety, environmental, etc. The "Big-Room" concept is used to facilitate the dynamics of a project team that includes all the stakeholders in this central way of working. The objective is to have a resulting design that makes use of sustainable materials and methods and that can be built safely within defined cost parameters. Many of the design and built solutions satisfy BREEAM and LEED standards, the two leading environmental assessment methods. The new sustainability strategy "Living Building Challenge" is also mentioned.

INTRODUCTION

The Construction Industries in many parts of the world have seen change to offer alternatives to the traditional design-bid-build project delivery system. This momentum encouraging change away from traditional design-bid-build can be traced back to Sir Michael Latham report, "Constructing the Team" 1994 and Egan 1998. Today, many government agencies are insisting their construction projects to be designed and built by a collaborative AEC team assisted by tools that provide open shareable asset information. The debate continues as to what clients should demand in terms of deliverables from this new way of working. In particular clients and government around the world are insisting on buildings that have minimum impact on the environment.

A significant driver (Teichholz, 2004) is that while other industries increased their productivity in the last half of the last century by 120%; the construction industry underwent a 20% decrease. A study (Gallagher, 2004) carried out at the NIST Institute showed that poor data management and data exchange also had a significant impact on the final cost of construction projects. Therefore, to fully consider design alternatives that satisfy the many, often competing constraints, they must be supported by timely knowledge and product information. This is the focus of the author's research summarized in this paper.

Government Driven

In the USA, the General Service Administration (GSA) through its Office of Design and Construction (OCA) is responsible for $1.7b of new construction work in 2012. Starting in 2003, through its Public Building Service (PBS), it established a 3D-4D-BIM policy that is now supporting applications in over 100 projects. Similarly, the UK Government Building Information Modeling (BIM) Strategy group has debated the construction and post-occupancy benefits of BIM (Building (asset) Information Modeling and Management) for use in the UK building and infrastructure markets over the next 5-year period in terms of cost, value and carbon performance. It has now mandated fully collaborative 3D BIM as a minimum by 2016, and the need for efficiency and industry reform to realize a 'cost reduction of 20% during the term of the current parliament'. This mandate will drive considerable changes in the traditional processes and practices of the UK AEC industry since it is estimated that today, less than 10% of firms use BIM software in the UK as compared to 60% in the USA.

ENVIRONMENTAL PERFORMANCE

If we accept that to be sustainable means living within the supply capacity of regional and global environment, then there is a huge responsibility on the designers and builders of our built environment to plan, design, build and operate these buildings and structures with full regard to those limited global resources. Resource conservation, recycling, energy efficiency and renewable energy are all focus areas, however, selecting sustainable and 'green friendly' materials is the essential key to unlock a maximized, sustainable design. Selecting sustainable, durable and recyclable materials both for the permanent structure and temporary systems required to build that structure, should be involved with every part of the

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process. Having access to knowledge of the environmental impacts of materials selected is essential to produce an effective design, i.e. data on carbon dioxide levels, energy usage, cost, health benefits and resource impacts.

LEED vs. BREEAM - In the construction world, there are two significant programs that have held a more profound impact on the issue of sustainability and environmental design, the United States Green Building Council's Leadership in Environmental Design (LEED) and the United Kingdom's Building Research Establishment Assessment Method (BREEAM). In the past two decades each program has developed significant differences (fig 2) in their detailed methodologies, scope and emphasis of assessment, metrics, and certification processes, and thus each has experienced varying levels of success and influence, nationally and globally. BREEAM is "the world's foremost environmental assessment method and rating system for buildings, with 250,000 buildings with certified BREEAM assessment ratings and over one million registered for assessment since it was first launched in 1990". In the past 23 years alone, BREEAM has expanded massively, going from a 19-page BRE report with 27 credits available, to a massive 350-page technical guide with 110 total credits, with more than 116,000 certified buildings and 714,000 buildings registered, located within the United Kingdom, and over 300 outside the country (Parker, 2009). BREEAM and LEED standards cover all main building types, including retail, offices, education, prisons, courts, healthcare industrial, specialized buildings, and multi-residential complexes. The BREEAM assessments are applied by many public sector organizations within the United Kingdom: Office of Government Commerce buildings require working to a rating of "Very Good" for refurbishment projects and "Excellent rating for new build projects. Developed by the U.S. Green Building Council (USGBC) in 1998, LEED is "a voluntary, consensus-based, market-driven program that provides third-party verification of green buildings" ("LEED"). Since its inception, LEED certifies 1.5 million square feet each day and has grown to encompass more than 52,000 participating projects in 135 countries, comprising more than 9.9 billion square feet of construction space ("About USGBC"). At its core, LEED took the structure and topics from BREEAM and adopted them to the U.S. market, introducing new and more effective concepts to environmental assessment. One of the novel adaptations of LEED feature is the requirement that building owners are only awarded with certification once the building is completed and can be further allotted additional credits for including innovative designs not already acknowledged under the scheme. The Hallmark of the LEED accreditation scheme is that it is an open and transparent process where the technical criteria proposed by the LEED committees are publicly reviewed for approval by the more than 15,000 membership organizations that currently constitute the USGBC.

Scheme	Weaknesses	Strengths
BREEAM	• Very exact requirements • Complex weighting system • Market profile • Cost of compliance	• Allows comparison and benchmarking of different buildings • Independently audited • Adjusted to UK legislation and UK culture • Can assess any building with the Bespoke version
LEED	• Based on US systems • Intense documentation required • No independent audit of the assessment • Mixing building function and form is difficult to assess	• Strong marketing gets the message through • Lots of information available • No need for an assessor and training

Fig 2 - *A comparison of strengths and weaknesses between BREEAM and LEED schemes (Parker).*

VDC, BIM and IPD

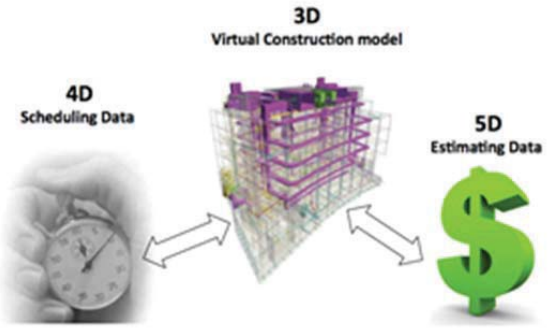
Virtual Design and Construction (VDC) is a collaborative, integrated process that considers both design and construction using a 3D BIM models in combination with schedule data (4D) and cost estimating data (5D) (fig1), a virtual object is created even before construction starts. As such, it serves as a shared knowledge resource for information about a facility thereby forming a reliable basis for decisions during its lifecycle from project inception onwards. Model, schedule and cost (GSA.2011) have to be coordinated from the beginning. VDC and BIM have to be implemented from the beginning of a construction project in order to increase the quality of the object, the organization, and the process during the building life-cycle. An important basic requirement for the model-based work method is a sufficient amount of information from the very start of a project. In particular, the criteria and constraints of the various contributors need to be articulated and discussed as the model builds. For the approach to work effectively it is essential to include the experience of construction managers to maximize project benefits from the execution experience. The result is a win-win situation for all members of the team. Furthermore, the building owner has security in terms of cost and schedule as well as optimized operation. During this phase the 3D, 4D or 5D models with a level of detail appropriate for execution are created.

Integrated Project Delivery (IPD)

Integrated Project Delivery (IPD) from conceptual design stages is the key to full consideration of sustainable features. The Integrated Project Delivery Team offers a solution-oriented approach. At a very early stage (project development, pre-draft phase) the entire planning (design) is carried out by a team that involves not only an architect and a structural engineer, but also consultants in the areas of construction management, MEP engineering, energy technology, building physics, acoustics, façade

construction and, depending on the type of project, further specialists. The "Big Room" concept can be used to facilitate the process, where all the key project participants, including the client, collaboratively work in the same room to define the sustainability and cost goals for the project. They then evaluate satisfying some of

Figure 1: Relation between 3D / 4D / 5D models



these goals through using local resources; assessing the opportunities presented by the site itself, and selecting materials that are minimal polluters, sustainable and recyclable, etc. Similarly, just as the cost and time to build aspects are driven down by collaborative team efforts through many iterations of considering alternative materials, layouts, component analysis, etc. the sustainability aspects can be analyzed with the goal to eliminate, reduce and change the use of materials and components that increase environmental inefficiencies. Next, the functional requirements of the structure are reviewed to see if it is possible to reduce the demand from that standpoint, i.e. efficient envelope design, solar and efficient lighting, construction systems required to build, energy requirements, life-cycle maintenance costs, air quality health impact, design for safety, etc. In the "Big Room" collaborative design environment, supported by responsive decision analysis support tools, the list of possibilities to refine the design is wide-ranging. The resulting design will bear a high degree of confidence that in regard to material and component efficiencies, sustainability, cost and time to build, it will achieve its objectives. Throughout the process, and during future use of the structure, continuous efforts will be made to reduce waste, improve health, use economical recycled and environmentally benign materials, and reduce the generation of pollutants.

Collaboration of the project team

Through the collaborative usage of the BIM model and IPD, this work method leads to a collaborative, integrated and transparent construction process. All communication goes back to the central model. The model is shared among all project team members and it serves as a common, rich database where all information is structured managed and maintained. Therefore, the amount of redundant data is reduced and repetitive data that already resides in the model can be used by all participants. It also acts as an excellent team building tool. A shared, visual model to externalize and share project issues is a valuable team-building tool. This rich data model on the completion of the project can be handed over to the Facilities Management team who provides the experience for operating and ensuring economic building performance.

COMPUTER AGENT RESEARCH

The author's research has investigated the necessity to introduce information and knowledge into the model at appropriate times. For the VDC system to work effectively, requires domain information, data and knowledge to be available in the system when required for solving problems, analyzing alternatives and making final decisions.

Pohl (1993) concluded that the design process could be characterized by five functional elements:

(i) Information - a search for relevant information that includes past experience.

(ii) Representation - the methods and procedures designers utilized to solve design problems relies on their ability to identify, understand and manipulate objects.

(iii) Visualization – that is important since traditionally, some form of graphic media is used to convey design intention, generally in the form of drawings. Drawings, however, are often inadequate in portraying information and can lead to erroneous conclusions, with many misinterpretations and inappropriate conclusions resulting.

(iv) Reasoning - that is central to the design activity. The ability of designers to solve problems is dependent on their interpretation of the issues and the dynamic changing relationship between these issues, often requiring different expertise to be drawn into the process.

(v) Intuition – in the design process, is often the spontaneous reaction to a thought process that diverts many areas of the human brain. The new generation of design tools e.g.

Revit and Navisworks, assist representation and visualization. However, bringing relevant information into the decision environment in a timely manner is a key to success.

Objects and Attributes

Having the ability to view the artifacts used in the design model as a series of objects, which have implicit attributes and features, gives scope to analyze the design in depth regarding such aspects as manufacture, constructability, cost, schedule, quality, safety, etc. All participating domains reasons with objects, in various groups that can

be termed super-classes, which in turn are composed of various classes e.g. methods, actions, activities, construction resources, costs, etc. Objects within each class could encapsulate knowledge about such things as its own function, its relationships with other objects, its behavior within a given environment, what it requires to meet its own performance objectives, how it might be manipulated by the designer within a given design problem scenario, etc. This knowledge is contained in the various representational forms and protocols of the object, e.g. factual data, rules, standard solutions, etc. Object models would be common to architects, engineers and construction managers and could be added to by any of these disciplines. It represents the static, structured, data aspects of the system that can be stored in object libraries.

Figure 3 Super-class structure

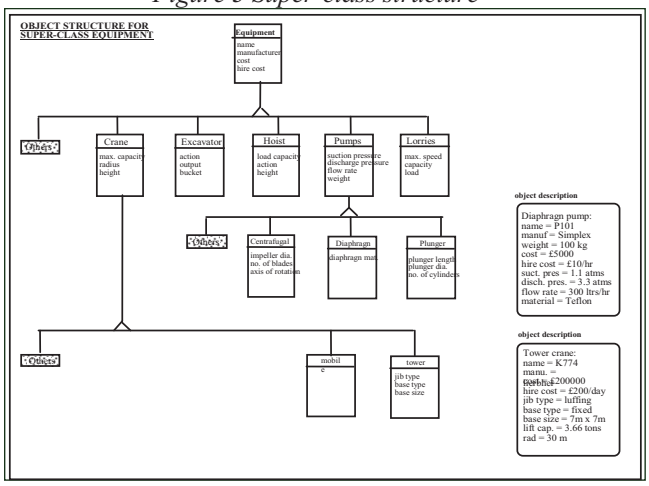


Figure 3 illustrates the more dynamic aspect of the system and indicates how attributes are encapsulated within construction super-class objects; in this case, the super-class "equipment" is used. Attributes include not only the shape and related geometrical features of the object, but also non-geometric properties and characteristics such as functions, materials, cost and performance. Within the super-class, 'Equipment' all classes of equipment can be represented (e.g. excavators, cranes, pumps, etc.). Each class might have a number of associated types (e.g. with pumps there might be centrifugal, diaphragm, etc.), many different types of attributes (e.g. flow capacity) could then be defined dependent on the level of problem solving and specification of final generated information.

Intelligent Computer Agent

Jones (1998) proposed a co-operative design agent environment composed of agent families representing the AEC participants, the client, and extendable to all the stakeholders to the project. Intelligence in the context of this research implies that the design system has some means that allows it to anticipate the data needs, information needs or knowledge needs of the human designer (in this case the integrated team). The system would act as an intelligent assistant to the evolving design, creating and aiding the collaborative team and freeing them from being overwhelmed with untimely information and knowledge. Providing such assistance requires an understanding of the various participants' knowledge requirements, the factors that constrain their decisions and the criteria under which they work. Pohl (1993) called this an Intelligent Computer Assisted Design System (ICADS). The ICADS approach was tested in several working models (ICADS-DEMO1 (Pohl, 1989), ICADS-DEM0 2 (Pohl, 1991), AEDOT (Pohl, 1992). These have provided computer scientists and practitioners with a useful test bed for the development of a body of knowledge relating to software and hardware computer architecture, theoretical concepts and technical implementation issues.

The characteristics such computer agents would possess are:

(a) The agents would be programmed with appropriate problem solving protocols.

(b) Agents would only be considered intelligent when they possess the capacity to plan their own actions. Intelligent agents would therefore have implicit domain knowledge, knowledge of their own needs, knowledge of global goals, the ability to communicate and the ability to take action. They would also have access to objects, which are information entities, but unlike agents, cannot take action. They would bring appropriate domain information and knowledge into the VDC.

(c) Different 'Families' of computer agents can be constructed that would support each domain. See section on 'Agent Families'

(d) Sub-tasks resulting from decomposing the problem are distributed to different domain agent families with the intention that these agents assist the human integrated team participants (termed in the research 'human agent').

(e) Each domain family of agents would operate in a narrow domain providing support to requests for assistance. These agents would range from simple to complex processing units each rationally working toward a single global goal or towards separate individual goals that interact. Acting independently in a self-regulating manner, they exist to express opinions about the current state of the design solution in regard the key criteria and constraints of that discipline. The intention is to change incrementally the current state of the design through the interaction among the various agents within the environment. However, the goals are set by the human agent with advice from the various autonomous agents including agent representation from the client. The criteria and constraints of the various participants would be continually analyzed to find a best solution.

(f) Agents representing many disciplines would use their local expertise and available resources to work in parallel

on different or co-coordinating tasks to arrive at a solution in the following ways:
(i) They would act as co-operative search agents that liaise with information knowledge bases in the search for alternative solutions.
(ii) Alternatively, they would act as evaluators and solution proposers to express opinions about the current state of the design solution or they would give continuous background monitoring and evaluation of the evolving design solution including conflicts.
(iii) They would be designed to have implicit domain knowledge, knowledge of their own needs, knowledge of global goals, the ability to communicate and the ability to take action.
(iv) Typically, each agent would be represented at the level of detail at which the design facilitator or human agent wishes to reason about the designed system.

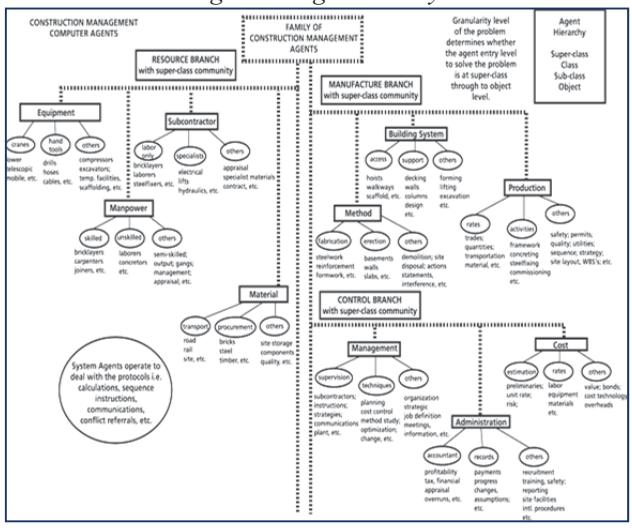
Agent Families

Complete 'families' of computer-agents that represent a particular domain will be built e.g. architect, interior designer, structural engineer, client, landscape architect, safety manager, quality manager, environmental manager, finance, mechanical and electrical engineer, construction manager, project manager, etc. For instance, the family of computer agents and objects would represent the construction management domain (fig 4) and their problem solving activities associated with the production problems of a specific project. Within each family specific agents' would monitor and offer assistance regarding criteria and constraints imposed in the areas of environmental, quality, safety, cost, production time, etc. There could be a 'Safety' agent residing in a number of domains i.e. Architect, Construction Manager, Project Manager, Quality Manager, each would be representing the criteria and constraints of that domain. However, design and construction solution development assisted by computer agents is not intended to automate the design process but rather to pool contributing domain expertise in the search for the 'best-value' solution. This interaction enriches the environment with information about the current design state and how it relates to project requirements. In this process the integrated team would direct and guide the efforts of all computer agents to advance the current state of the project solution towards a best-value design solution that is acceptable to all domains computer agents' and the inter-disciplinary project team. The role of the designer or project leader would be that of principal long term or strategic planner while agents would focus mainly on short-term activities. One important advantage is that alternative design or construction methods could be rapidly evaluated.

Family Tree -'CM Agents'

As stated, a family of Construction Management agents that would be designed to sit co-operatively among architectural, engineering and a variety of other specialized agent families. This research has identified three branches of super-class agents (fig 4) that reside under the Construction Management family:
(i) Resource branch.
(ii) Manufacture branch.
(iii) Control branch.
Each branch would include domain specified super-class agent communities that would divide into agent classes, which represent the entire problem solving activities of that super-class. Each super-class is divided into classes and sub-classes with their relevant object libraries. In the investigation (Jones, 1998), agents representing activities associated with a reinforced concrete building are used. However, once built this family of agents can be used again on other projects and is expandable by adding agents' or changing agents' for other types of buildings.

Fig 4 CM Agent Family



CONCLUSION

The integrated model based approach will positively influence construction in the 21st century. Many positive experiences and case studies are beginning to confirm the benefits. Central to these improvements is virtual design and construction assisted by rapid information systems in this research defined as intelligent computer agents. Governments around the world are insisting design delivery and project management use BIM tools and IPD strategies. The results of the author's earlier work in Intelligent Computer Agents (Jones 1998) can be linked to present day VDC. In this way, a collaborative team has the tools and information to interrogate and solve many of the cost, constructability, sustainability, time, quality,

environmental and safety, etc. issues before construction commences, and continue that monitoring throughout the construction process. At the end of the project, all captured information can be organized and passed to the facility operations team.

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THERMAL COMFORT IMPROVEMENT UNDER METAL SHEET CONSTRUCTION USING INDOOR VEGETATED WALL SYSTEM

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ABSTRACT

Metal sheet is a common material used for residential self-constructed top storey roofing and walling in Taiwan due to its inexpensive and fast construction nature. Over 80% of residential buildings using metal sheets to gain more indoor spaces on their rooftop. Due to the nature of high heat conduction, the interior of metal constructed space without insulation would result in over heating in summer and over cooling during winter cold wave. The study proposed indoor vegetated wall system as one of the passive strategy for improving interior thermal comfort of metal enveloped space while operated in natural ventilation mode. The research quantified the thermal effect of vegetated wall by experiment carried out in two full scaled laboratories and also by means of building simulation. Adaptive thermal comfort model proposed by ASHRAE was adopted to evaluate the indoor thermal comfort condition. Experimental data were used for assessing the degree of over cool alleviated by vegetated wall during cold wave period. For the purpose of long-term thermal comfort analysis, building energy simulation tools, EnergyPlus, was utilized to analogize vertical greenery effect on hourly indoor thermal conditions. The validation of the simulated values of indoor thermal variables against the full scale experiment result revealed an acceptable deviation. Therefore, the simulated data were used to further evaluate annual long-term thermal comfort during both hot and cold period base on methods proposed by ISO 7730. The decrease in discomfort as well as degrees of severity due to the application of indoor vegetated wall were discussed. Primary results show that although there are slight increases in relative humidity, it can be concluded that occupants would benefit from utilizing indoor vegetated wall in improving thermal comfort of metal constructed spaces under natural ventilation circumstances.

INTRODUCTION

With limited land space and highly urbanized living style in Taiwan, many detached or row houses often would construct metal sheet shelters on the rooftop for gaining more living spaces, which characterized the cityscape of Taiwan. Favored due to the low cost and the easy construction process, metal sheet becomes a prevailing post-construction material. However, due to the nature of high thermal conductivity of metal, the interior space would be hotter in the summer and colder in the winter, as compared to if reinforced concrete was used. As a result, indoor cooling via air-conditioning apparatus become less energy efficient. Therefore, in order to improve the thermal comfort of indoor condition and to reduce the energy consumption of air conditioning, the study aims to explore the effect of thermal comfort improvement under metal sheet construction with indoor vegetated wall (VW). The study adopted a full-scale experimental method to monitor the indoor thermal condition. Moreover, for the purpose of long-term thermal comfort analysis, hourly energy simulation program, EnergyPlus, was utilized to analogize vertical vegetated wall effect on indoor thermal conditions. The application of indoor VW is a cost effective way to improve indoor comfort as well as to increase environment amenity. The study quantified the thermal effect of VW through on site field experiments.

Vegetated wall (VW) system is a wall system consisting of plants, soil and modular containers and is isolated from the target wall. In 2011 Yoshimi simulated the indoor environment with indoor VW system via ECOTECT software with thermal conduction properties of the VW's materials (Jury Yoshimi, 2011). In this study, the thermal effect of vegetated wall was quantified by experiment proceeded in two full scaled laboratories and also by means of building simulation. The most credible method to characterize indoor thermal discomfort for naturally ventilated space is the thermal adaptive model proposed by ASHRAE Standard 55 base on ISO 7730. (Van Hoof, J., 2008) suggested that human thermal perception is capable to adapt to local climate and their thermal comfort neutrality temperature (T_n) is much dependent to outdoor long-term averaged ambient temperature when indoor space is mainly operated in natural ventilation mode. de Dear and Barger had also recommended using adaptive thermal model for evaluating the indoor thermal comfort under natural ventilation condition. (de Dear.Brager.,1998). The models are shown in equation (1) and (2). The adaptive model used herein was also adopted by the American Society of Heating, Refrigerating, and Air conditioning Engineers (ASHRAE) as standard for evaluating thermal comfort in free running buildings

$$T_{om} = (T_{od-1} + T_{od-2} + \cdots + T_{od-30}) \times 30^{-1} \quad (1)$$

$$T_{n(ASHRAE)} = 0.31 \cdot T_{om} + 17.8 \quad (2)$$

where T_{om} is monthly average temperature in previous 30 days; $T_{(od-i)}$ is daily average temperature i day before the calculated day; $T_{n(ASHRAE)}$ denotes to thermal adaptive model's T_n proposed by ASHRAE.

Because the humidity had an impact on indoor comfort, traditional predicted mean vote (PMV) model

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(ASHRAE, 2010) was also adopted for indoor thermal evaluation.

The ISO 7730 (ISO, 2005) recommends the estimators for evaluating long-term general thermal discomfort, taking into account both the frequency and severity of discomfort. The estimator with degree hour measure ($wf_{(dh)}$), which takes discomfort to be linearly proportional to the degree by which the discomfort threshold is exceeded by the upper/lower limit of thermal comfort range, is as in (3). When the actual indoor operative temperature (T_{ot}) falls beyond the lower or upper limit ($T_{ot,limit}$) of the specified comfort range, the difference is taken, and a weighting factor is applied to quantify the thermal discomfort. The warm and cold period severity of long-term discomfort ($I_{(warm)}$ and $I_{(cold)}$) are therefore estimated by applying weighting factors ($wf_{(i)}$), as in (4) and (5).

$$wf_{(dh)} = 1 + \frac{|T_{ot} - T_{ot,limit}|}{|T_{ot,n} - T_{ot,limit}|} \quad for\ |T_{ot}| > |T_{ot,limit}| \qquad (3)$$

$$I_{(warm\ period)} = \sum wf_{(i)} \cdot t \quad for\ t_0 > t_0, limit \qquad (4)$$

$$I_{(cold\ period)} = \sum wf_{(i)} \cdot t \quad for\ t_0 < t_0, limit \qquad (5)$$

MATERIALS AND METHODS

Full-scale laboratory setting

The factors affecting the indoor thermal environment are complex and the physiological function of plants is difficult to control. Thus in order to observe the effect of indoor vertical vegetated wall to the indoor environment, the study adopted two metal sheet container houses as full-scale laboratories. The experimental and control sets of the experiment are shown in figure 1 and the physical properties of the laboratory is presented in table 1. The physical shape and the container envelope's thermal property of both groups were of the same condition. Outdoor HOBO weather station was set up in the neighbourhood.

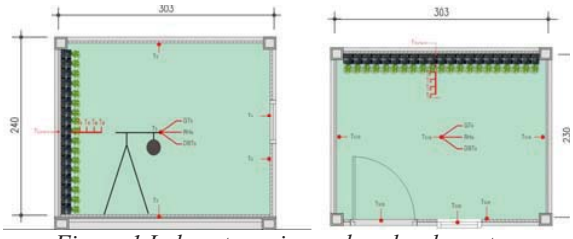


Figure 1 Laboratory size and probes layout

Table 1 Laboratory size

ITEMS	PARAMETERS
Area	7.30 m^2
Wall material	k=45 W/(m.k)
Window glass	SHGC=0.82
	U=5.78 W/m^{2}K
Aluminum	k=210 W/(m.k)

Experiment method and equipment

As indoor thermal environment varies under different physical conditions, we adopted automatic sampling method to measure physical environmental variables such as indoor air temperature, relative humidity, average radiation temperature, etc. in every 10 minutes. The sensors and their accuracy are summarized in table 2. The indoor air thermometer and globe thermometer were placed 110 cm high above the ground in the middle of indoor environment. Three thermocouples were also set up normal to the indoor VW surface at every 10 cm intervals are shown in figure 1.

Table 2 Sensors and their measuring accuracy

SENSORS	SENSOR ACCURACY
T-type thermocouple	±0.05%
Air temperature sensor	±0.35˚C at 25˚C
Relative humidity	±2.5% RH
Soil Water Content meter	±0.041 m^3/m^3 (±4%)
Ambient air temperature & relative humidity sensor	±0.25%

Continuous observation was made throughout the experiment from January through April in 2013. The metal sheet houses may become overheated or overcooled due to high heat transmittance (U-value) and low thermal capacity. Therefore, the wall of metal laboratory is subject to the weather condition. A weather station was set up outside the experimental laboratories to observe the meteorological data during the experiment period. In an attempt of eliminating the deviation caused by the weather, representative days were selected for analysis in every month and during the period of winter cold wave. Days with relatively high and stable solar radiation distribution were given priority and chosen as candidate days. The measured values from the candidate days with similar average daily and monthly temperature distribution were then filtered for further analysis. The February 9th and 10th during winter cold wave period and the March 8th and 9th in spring were chosen as representative days. The weather data of these days was presented in table 3.

Table 3 Outdoor weather condition of the selected representative day

PERIOD	DATE	DAILY MEAN TEMP. [°C]	MONTHLY MEAN TEMP. [°C]	MAX. SOLAR RADIATION [W/M^2]
Cold wave period	2/9	14.1	18.4	600.6
	2/10	16.4	18.4	611.9
spring period	3/9	20.7	19.4	718.1
	3/10	20.9	19.4	751.9

Long-term simulation of indoor thermal comfort

Simulation techniques were introduced to evaluate and quantify the annual long term performance of VW in improving indoor thermal comfort, as measurements were only taken during winter and spring. EnergyPlus with its capability of doing sub-hourly iterative simulations of thermal balance between outdoor and the indoor environment was adopted. The overall thermal conductivity of indoor VW was theoretically calculated to analogue a composite wall. Therefore, indoor VW is regarded as a composite construction material and is available to model and simulate in EnergyPlus for year round indoor thermal conditions. For the purpose of validating the simulation results with actual measured indoor thermal condition values, the same laboratory was modelled in EnergyPlus. Since the full-scaled experiment period of the study was taken place in the first half of the year 2013, meteorological data including precipitation, solar radiation, dry bulb temperature, relative humidity, and wind velocity observed via on-site weather station from January to April in 2013 were converted to meteorological year in EnergyPlus Weather File (EPW) format. The EPW was afterwards fed to EnergyPlus to validate the simulation.

Table 4 operation schedule of model component

ITEMS	PARAMETERS
Lighting density	10.13 W/m^2
Lighting schedule	On: 08:00-17:00 Off: 18:00-07:00

RESULTS AND DISCUSSIONS

Indoor thermal environment analysis

The data of the experimental lab (with VW) and the control lab (without VW) was obtained and compared. Figure 2 illustrates that the air temperature observed 10 cm in front of the VW was 0.1 Celsius degrees higher than the one without VW of the same location at 8 a.m. on February 9th during the winter cold wave. On the contrary, it was 0.64 degrees Celcius lower for the case with VW during a typical spring morning. This indicates that indoor VW is capable of maintaining relative constant indoor thermal condition during cold wave period.

Based on the experimental results observed, it shows that the indoor temperature was influenced by the indoor VW. The variations of indoor temperature during daytime and night time were further discussed. The analysis of the representative day in the period of winter cold wave was presented in figure 3. Warming effect was observed when at cool night, interior temperature for the lab with VW could be 0.3 Celsius higher than that of the lab without VW. In contrast, during daytime, the interior temperature with VW could be 1.0 Celsius lower than that of the lab without VW system installed. The results clearly demonstrated that the VW has more obvious effect on cooling the interior space than to keep it warm, which could be beneficial for hot summer season.

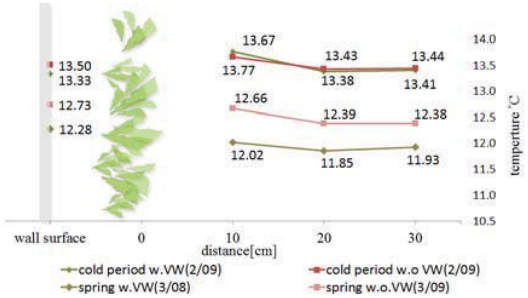


Figure 2 Indoor air temp. variation away from the wall on 2/9 & 3/8 8:00 a.m.

On a typical spring day (hot period), the analysis of measured data showed that the greatest difference in temperature occurred at 11 am. The indoor temperature was 28.88 Celsius with VW while the temperature was 30.08 Celsius for the one without VW. The difference showed that VW has a cooling effect to a degree of as much as 1.92 Celsius. In contrast, at 6:00 a.m. in the morning, largest difference in temperature was observed. The indoor temperature was 22.35 Celsius with VW while it was 19.21 Celsius for the one without VW. It showed that VW has a warming effect of 3.15 Celsius when the outdoor temperature is cooler or when there is no solar radiation. As in figure 4 illustrates, the warming and cooling effect of indoor VW is more effective during spring season.

By observing the measured data from the full-scaled experimental settings, physical changes in the condition of indoor thermal environment would change differently depending upon whether there was a VW system as well as the outdoor temperture/solar conditions. In addition, the VW has mild warming effect during nocturnal period but has substantial cooling effect during daytime.

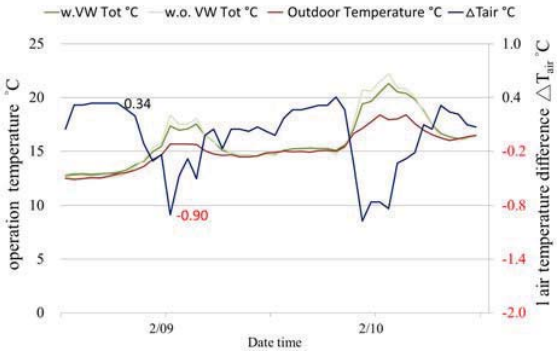


Figure 3 Indoor temperature differences during cold period

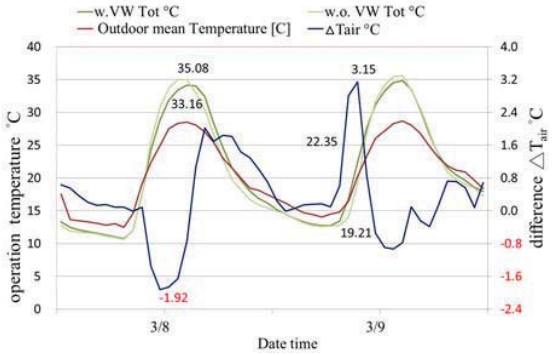


Figure 4 Indoor temperature differences during hot period

Table 5 Frequency of discomfort while assessed with thermal comfort adaptive modal

OUSIDE COMFORT ZONE	COLD PERIOD		HOT PERIOD	
	w.VW	w.o.VW	w.VW	w.o.VW
percentage	89.8%	85.7%	75.5%	85.7%
hours	44	42	37	42

Frequency and severity assessment of thermal discomfort

The severity of discomfort was assessed by the total hours that exceed by the upper/lower limit of thermal comfort range. According to figure 5, the $I_{(dh)}$ of VW case is generally less severe than the case without VW during the cold wave period. The value of $I_{(dh)s}$ are 170.33 degree hours and 184.17 degree hours respectively, which is 7.5% less severe than the case without VW installed. It suggests that VW system is able to provide more insulation effect and hence keep the indoor temperature at a higher degree than the case without VW. In spring (hot period), the severity of control group is 150.16 degree hours, which is more than that of the VW case (127.73 degree hours) by 17.6%. It shows that the indoor space without VW in hot days might be severely over-heated.

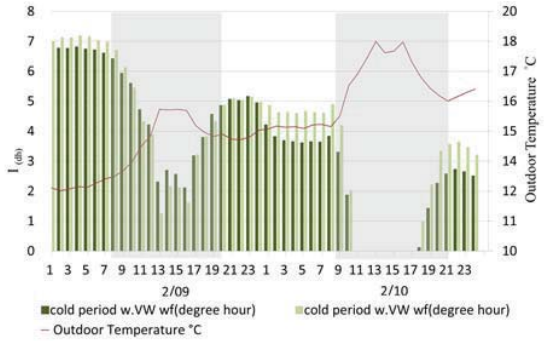


Figure 5 The severity of discomfort during two days of cold wave period

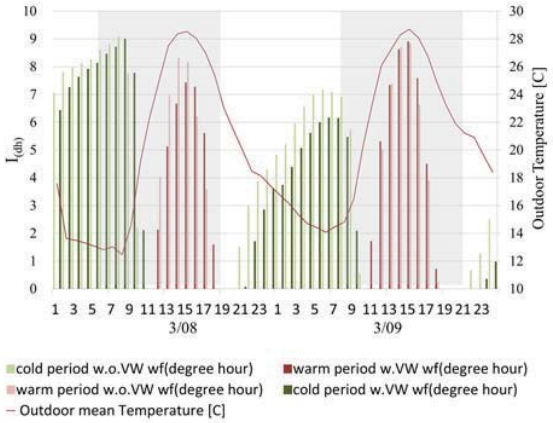


Figure 6 The severity of discomfort during two days of spring (hot) period

Table 6 The severity of long-term discomfort

SEVERITY OF LONG-TERM DISCOMFORT	COLD PERIOD		HOT PERIOD	
	w.VW	w.o.VW	w.VW	w.o.VW
$I_{(dh)}$	170.33	184.17	127.73	150.06

In general, there is a clear difference between the seasons in Taiwan. Indoor VW system can improve thermal comfort in the hot period. But while in the cold wave period, it is recommended that VW system being utilized in the space only used in the daytime such as office for the reason that it might be over cooled when outside temperature is low.

Long-term thermal comfort analysis via simulation

Since the experiment period was from January to April in 2013, yearly long-term evaluation of indoor thermal comfort is assessed mainly by hourly simulation via EnergyPlus. Before the simulation is adopted, simulated results should be validated by actual measured values first. According to the Juri Yoshimi's (2011) research, he mentioned a model method to simulate VW in hourly energy simulation tools. The research analoged and integrated the material of VW into traditional construction. The input parameters of VW for modelling are a series of composite values anologizing the composite materials of HDPE vertical greenery supporting structure and the growing medium (soil). The parameters, including thermal conductivity, thickness, density, and the specific heat, as well as their values used are listed in table 7. The experiment indicated that the soil affected the heat conductivity of vegetated wall much more than plants did. As a result, plants were not considered as components in modelling the VW in the simulation model.

In order to verify the output accuracy of the simulated model, root mean squared error (RMSE) was adopted for verifying the simulation bias. The outdoor meteorology boundary used for simulation was the same value observed on-site on March 8th. Simulated values of indoor operative temperature were

compared with the measured values. The resulting RMSE is only 3.26 °C, which is considered acceptable, indicating indoor thermal condition outputs via EnergyPlus simulation are reliable. After satisfactory validation process, we further adopted hourly Taipei TMY2 meteorological data for year round simulation. Hourly indoor operative temperatures (T_{ot}) were obtained via EnergyPlus simulation output. These T_{ot}s were afterwards used for calculating the cumulative deviation from the upper/lower limit of the adaptive thermal comfort proposed by ASHRAE.

Table 7 Thermal properties of model components

LAYER NAME	THICK-NESS (m)	CONDU-CTIVITY (W/m-K)	DENSI-TY (kg/ m^3)	SPECIFIC HEAT (J/ kg-K)
steel	0.0003	45	7860	480
aluminum	0.08	210	2700	901
air gap	0.1	21.7		
VW supporting structure	0.0003	0.19	1500	128.4
Garden soil	0.09	0.52	1450	111.8

* The value of thermal conductivity of soil was estimated in consideration of the percentage of water contained

Annual analysis of long-term thermal comfort

Long-term thermal comfort was therefore estimated via simulation results. The severity of discomfort due to overheating of VW was 3,917.9 K-hrs and the severity of overcooling was 6,342.3 K-hrs. Whereas it was 7,819.9 K-hrs of overheating and 11,539.0 K-hrs of overcooling for the case without VW. This indicates that the overheat hours could be reduced by 3,902 K-hrs (49.9%) for metal sheet construction ultilizing VW. Also, the overcool hours could be reduced by 5,196.7 K-hrs (45.0%) in the metal sheet space with VW compared to the one without VW. The frequency of hours outside the comfort zone was 4.32% less than the case without VW in the warm period. In the cold period, the house with VW was 15.63% lower than the house without VW. Monthly values of the severity of thermal discomfort and the frequency of hours outside the adaptive thermal comfort range limit is illustrated in figure 7.

CONCLUSION

From the on-site full scale experiment results and the long-term thermal comfort simulation, several conclusions can be obtained as follows:

1. From ASHRAE adaptive thermal comfort model assessment, metal sheet enveloped spaces with VW system installed would provide more comfortable indoor thermal environment than the case without VW during the daytime in both cold wave and hot period.

2. The space with VW would have a more comfortable indoor thermal environment than a space without VW, at night in spring.

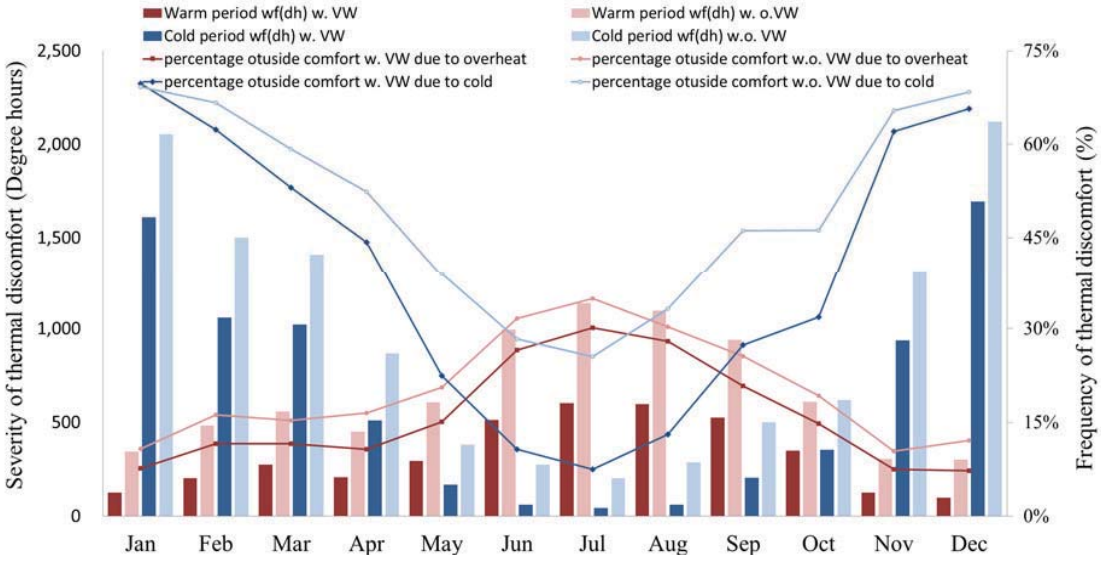
3. It was discovered that indoor VW is able to reduce the severity of overcooling and overheating. In summer July, indoor VW is able to reduce the overheat thermal discomfort by 532.3 K-hrs. In winter January, it is able to reduce discomfort by a maximum of 1827.3 K-hrs.

The nature of high thermal conductivity of metal sheet construction itself would inevitably result in overcooling and overheating phenomenon in subtropical Taiwan, where there is distinct winter and summer seasons. From the experiment and the simulation results, we discovered that for year round usage, VW system is recommended to be utilized for daytime usage type space, such as offices. But as far as severe cold wave period, indoor T_{ot} of VW system could be lower especially at nighttime, and is therefore not recommended for spaces of residential usage, when its primary occupied hours are in nighttime.

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Figure 7 Monthly value of the severity of long-term thermal discomfort and the frequency of discomfort occurrences



URBAN FORM ANALYSIS IN RELATION WITH BUILDING EXTERNAL HEAT GAIN ON DISTRICT LEVEL

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ABSTRACT

In recent years, urban areas have become denser, such that the climatic condition of cities differs greatly from the outlying area. This difference is the result of Earth's surface modification to buildings and streets. These changes have impacts on urban ambient temperature and the amount of solar radiation received by buildings envelope; where in the end these urban climate changes affect building energy performance on various scales.

Rather focusing on individual buildings, this paper examines the influence of urban form and density on both background climate and external heat gains received by the buildings on district scale. With a parametric study approach, hundreds of different urban geometry layouts were generated and simulated to understand both annual cooling demands and external heat gain through building envelopes.

This research highlights the importance of implementing a climatic study approach in urban planning at the early design stage, which could benefit planners on proposing better sustainable.

INTRODUCTION

Literature Review

Katzschner mentions that climate is an ever-present factor in a built environment and the study about climate condition is purposed to improve the climate condition and to reduce the negative microclimate effects (Katzschner 1998). The correlation between micro-climate conditions in an urban area and the buildings performance is clearly described by Givoni: the outdoor temperature, wind speed and solar radiation to which an individual building is exposed are not the regional 'synoptic' climate, but the local microclimate as modified by the 'structure' of the city, mainly of the neighbourhood where the building is located" (Givoni 1998).

In tropical climate, the recent increase of diurnal ambient temperature affects the thermal balance within the environment with sun overheating occurs all year round. Meanwhile, building occupants are adapting with air conditioning to achieve comfortable internal condition. For central urban areas, the amount solar receipt at the building surface and the dynamic nature of mutual shading between buildings can directly affect both the outdoor and indoor climate and therefore the associated building cooling load (Smith, 2008). While the consequence of the diurnal cycle on building performance can be mitigated through optimising the envelope construction and building systems, this does not account for the influence of the urban context.

In spite the obvious relationship between the urban forms and urban climate, there only few studies which attempt to bridge the role of building forms and its implication on energy demand. According to Baker and Steemers (see Figure 1), building design accounts for a 2.5 times variation in energy consumption, systems efficiency for a 2 times variation and occupant behaviour for a 2 times variation (Baker and Steemers 1992, 2000; Ratti et al. 2005). The cumulative effect of these factors can lead to a total variance of 10-fold. In practice, variance in energy consumption of buildings with similar functions can be as high as 20-fold. The question is, what number can we put for urban geometry times factor?

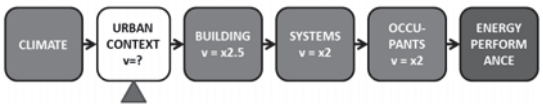


Figure 1 Factors that affect energy consumption in building according to Baker and Steemers, in which the urban context is yet to be quantified.

Salat (2009) investigated the impact of urban morphology from different urban fabrics, by comparing urban form and energy consumption. The study showed an energy-efficient urban area can reduce both energy consumption and carbon emission by a factor of two, which is very significant.

Wong et.al (2011a) used an air-conditioned office building to be simulated under different scenarios representing urban settings for the tropical climate. The result shows that increasing the surrounding building heights lowers the ambient temperature; consequently, this reduces 5% cooling demand, which is quite substantial particularly for a larger scale. Their previous studies have also illustrated the impact of urban forms on outdoor ambient temperature, which indicates that there is a strong linkage between microclimate and city physical form (Wong et.al 2010, 2011b). All these studies display the importance of urban geometry form on determining city's energy consumption.

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Significance of Study

This study examines the role of urban geometry with its focus on cooling load of office buildings and offers a new perspective on energy study at an urban scale by demonstrating that when urban context is considered during energy management, the overall performance of an urban system can be significantly improved.

Mills once proposed that examining the relationship between urban geometry and climate could employ the results of urban climatology into urban design guidelines (Mills, 2008). Within the same objective scope, this study highlights the role of urban geometry and local microclimate on building energy performance (both individually and collectively) while demonstrates that as we move towards a low energy future; the role of urban geometry becomes increasing significant. In the end, this research opens up the possibility on implementing climatic study approach into urban planning, where the combination of these two fields could propose planning strategies on creating more sustainable cities.

Parameters

Urban area geometry can be defined by its density and form. This study uses *Floor Area Ratio (FAR)* and *Site Coverage (SC)* parameters to quantify urban density; both have been widely known in urban planning terms. Meanwhile, other chosen parameters that also characterize the urban form are:

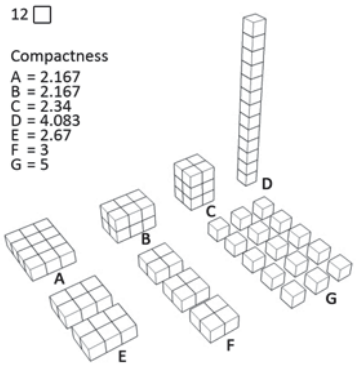


Figure 2 Buildings with same volume, but different compactness or surface/volume ratio.

- *Compactness* is the most direct geometric variable that deals with both form and solar insolation. It is equal to the surface area of the building's envelope over the volume of the building (Adolphe, 2001, 2009). This becomes important since the study was done under the tropical climate condition, compactness would have a major impact on heat transmission through the building envelope. Salat stated that volumetric compactness as one of the form factors which is useful for a thermal analysis of buildings since it influences their theoretical heating needs (Salat, 2011). Figure 2 illustrates how several buildings with the same volume have different compactness one to another.
- *Sky View Factor (SVF)* parameter is used in order to quantify and measure openness within an urban area. Deriving from the concept of "view factor", SVF is a geometric ratio that expresses the percentage of a point's field of view that is occupied by the sky as opposed to buildings, tree or any other object in the landscape (Schneider, 1992). The value is ranging from 0 (shaded) to 1 (open to the sky).
- *Sky Exposure Factor (SkyEF)* is used to account for the shading effect on a vertical surface by surrounding buildings in densely built urban centre. It is the ratio of the solid angle of the sky patch visible from a certain point on a building's facade to the solid angle of the hemisphere centred at the same point, and represents the "geometric definition" of SVF (Hii et al., 2011; Ji et al., 2011). The value is ranging from 0% (totally shaded) to 50% (fully exposed). Figure 3 shows how SVF differs from SkyEF.

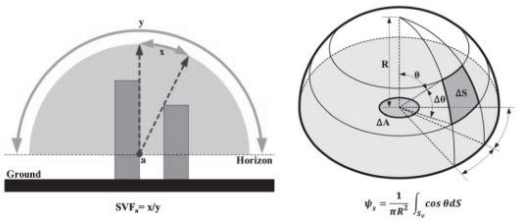


Figure 3 Sky Exposure Factor (left) and Sky View Factor (right) (Johnson and Watson, 1984).

METHODOLOGY

Software Utilization

For the purpose of this study, several tools were utilized for obtaining parameters and running energy simulation. Since the building energy simulation requires the localised weather data, quantification of external air temperature variation was done by using Screening Tool for Estate Environment Evaluation (STEVE) tool in conjunction with Geographic Information System (GIS). STEVE tool is an empirical model that calculates the maximum, minimum and average air temperature of a point of interest based on a 50m radius in an urban built up area in Singapore (Jusuf et al. 2007; Wong, Jusuf, 2008; Wong et al., 2011a).

Meanwhile, energy simulation was conducted by using IES, a dynamic building energy simulation software, which could perform multiple analyses related to environmental performance. IES has advantages such as has the ability to simulate the performance of multiple buildings within an urban context and altogether accounts for the mutual shading that occurs.

Methodology Flowchart

A parametric study involving urban texture variation was conducted to observe its implication on district energy performance (see Figure 4). Thus, these parametric study scenarios were simulated to understand the annual energy consumption and heat gain through building envelopes.

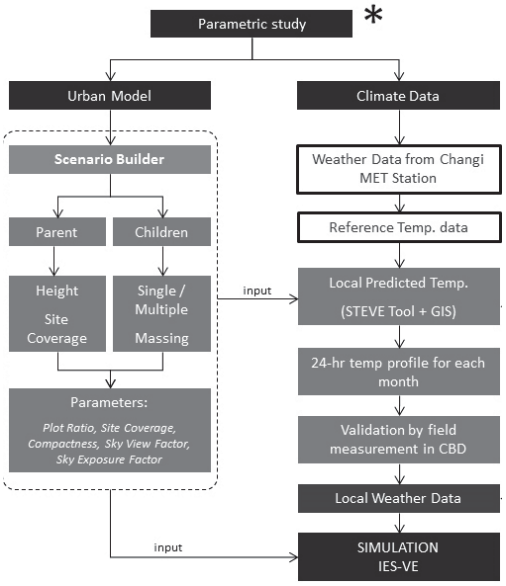


Figure 4 Research workflow on parametric study

After obtaining IES simulation results, the following step was to look into the cooling load data, which comprised external and internal load. As illustrated in Figure 5, the scope of this study was focusing on the heat load from the outdoor environment; hence, the analysis probed more detail on: (1) envelope conduction gain (2) solar heat gain, and (3) fresh air intake gain.

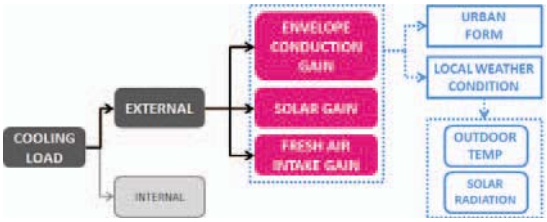


Figure 5 Analysis flowchart.

These three are the main external heat gain components, where the factors such as urban form and local microclimatic condition were expected to play roles on determining the amount of heat load. This study attempted to examine building energy loads (associated with office function), which were affected by two factors: (1) localized or urbanized climate condition and (2) solar insolation on building surfaces as a result of mutual shading provided by building groups arranged as rows to form streets.

The discussion of other factors such as façade materials, wind, and humidity were excluded since these parameters required more comprehensive research and another set of study.

Scenario Builder

The parametric study involved multiple scenarios, with density and forms differential. Figure 6 displays all scenarios options were assumed to be on the same district configuration, where buildings were put inside six plots of 100m x 100m, surrounded by 2 storey buffer buildings. This layout formed a hypothetical district of an urban area, which resembled the grid pattern of Singapore new central business district master plan.

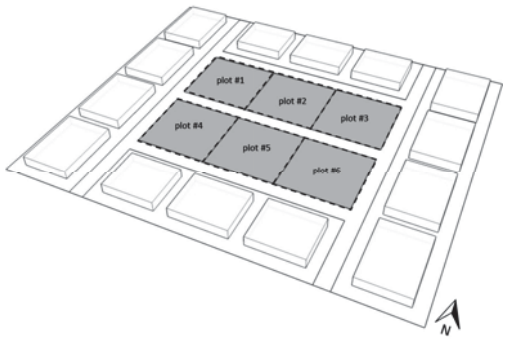


Figure 6 Typical neighbourhood setting for all scenarios.

Several parameters were used as the basis for scenario builder, such as Site Coverage (SC), Gross Floor Area (GFA), FAR, forms, and number of massing. In order to limit the number of scenarios and avoid complicated dimension values, a parent-child systematic scenario builder was made with the following steps:

1) Rectangular shape is the reference building form for every parent scenario within each plot. The sizing variation began by firstly adjusting the SC gradually from 20% to 80%, with 10% increment (see Figure 7).
2) The next step is to increase the building height by adjusting the number of floors, (floor-to-floor height is fixed at 3.5 m), starting from 2, 4, 6, 10, 15, and finally 20 storeys.
3) The definition of a 'child' scenario is the variation of building form apart its parent shape. Figure 8 illustrates how each parent scenario was transformed into several options of different building forms, preserving its parent scenario characteristics (site coverage, height, total GFA and volume).
4) There are two big groups, singular and multiple forms. **Singular type** comprised rectangle, slab, and plus shape building. **Multiple massing type** comprised the reference building splitted into 2, 4, 9, and 16 numbers of buildings consecutively.

5) Figure 8 displays the children scenarios schematic. While Figure 9 shows the generated examples.
6) IES calculated total cooling load and heat gain components of each scenario district.

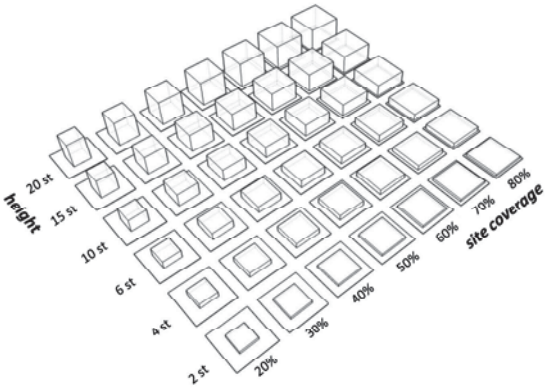


Figure 7 Compilations of all 'parent' scenarios.

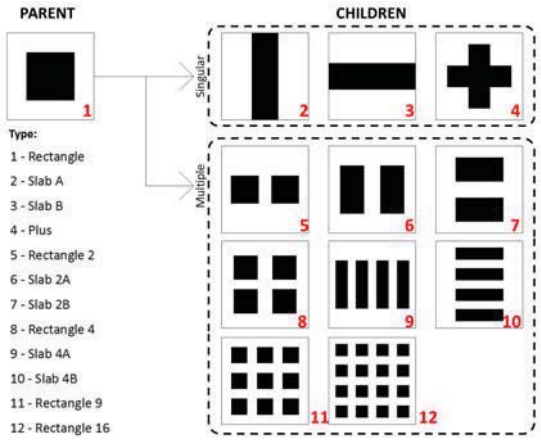


Figure 8 'Parent' and 'Children' concept flowchart; where each parent has 11 children scenarios with the same footprint, height, and floor area.

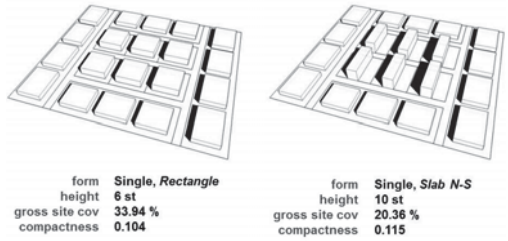


Figure 9 Samples of the generated urban layouts
Figure 9

Boundary Condition

The study dealt with non-domestic type, referring to typical office building in Singapore. The hypothetical building models were assumed to be operating on a 55-hour workweek (Lee et al., 2004). Lighting power density and ventilation rates were kept constant at 15 W/m^2 and 0.6 l/s.m^2 in accordance to local codes of practise (SPRING, 2006, 2009). The buildings were air-conditioned, following the normal working days occupancy; with cooling thermostat was set to 24^o C. Envelope construction (wall, glazing, and roof) was fixed for all scenarios, by maintaining 50 per cent window-to-wall ratio on every façade orientation.

SIMULATION RESULTS

At the time of writing this paper, the authors have done simulating scenarios with 20% and 80% SC, inclusive the height increments (2, 4, 6, 10, 15, and 20 storey). 132 scenarios have undergone energy simulation, which had provided both cooling load and external heat gain data. Due to technical reasons, type 4 and 5 results from 80% SC sets were excluded.

Local Outdoor Temperature Profiles

Predicted outdoor temperature from STEVE tool calculation for each scenario was transformed into annual temperature profile or urbanized weather data. The temperature profile difference between each scenario could be observed in the box plot displayed in Figure 10. The chart illustrates some examples of different building forms yielding different ambient temperature profile. This demonstrated the importance of implementing the local urbanized temperature profile for building energy simulation rather than using the data from a weather station, which might be located far away from the studied area.

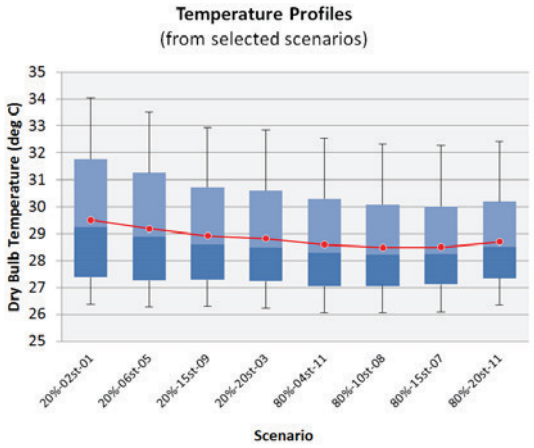


Figure 10 Temperature profile samples.

Load Percentage Difference

The results demonstrate the total load shown as a percentage difference (Δ%), which referred to total district load of the children scenarios compared to its parent (type 1 – rectangle). Figure 11 illustrates the cooling load percentage Δ% for both 20% and 80% SC sets. Each set had 6 parent groups of different building heights. Every group comprised 11 children scenarios (all had the same floor area, volume, and height as the parent scenario). The chart suggests that dividing a building into multiple masses (becoming less compact) would increase the cooling load.

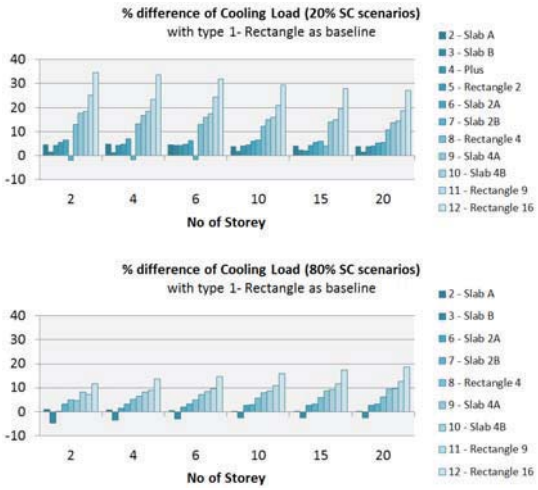


Figure 11 Cooling load chart for each parent group from both 20% and 80% SC sets.

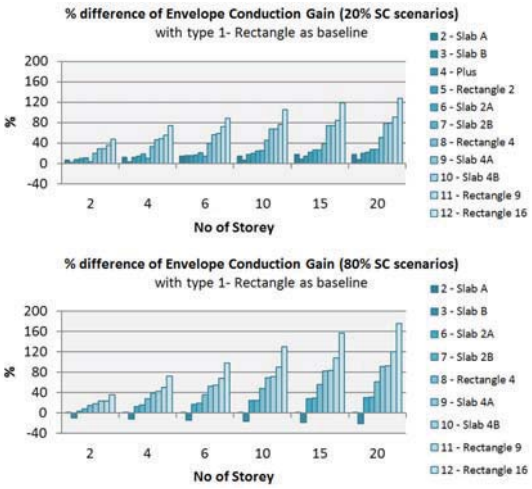


Figure 12 Envelope conduction gain chart for each parent group from both 20% and 80% SC sets.

For instance, the parent group of 20% SC and 2-storey high (20%-02st) showed Δ% between a single rectangular shape (type 1) and multiple 16 masses (type 12) was 34%. Consequently, the trend showed if the urban geometry became less and less compact, the cooling load increased (except for type 3, which showed a minus Δ%. This was because the type 3 urban geometry form (continuous horizontal slab) was more compact than type 1).

Within the 20% SC set, the cooling load started to increase drastically when the building was split into 4 masses (type 8), ranging from 10%-34%. While the 80% SC set generally showed a lower Δ% for each group, with maximum difference of 18.65% (type 12-type 1, 20-storey group). Further analysis of 20% SC set revealed that when building height increased, the Δ% within each group gradually decreased. For example, type 12 – type 1 difference in 2-storey group is 34%, while in 20-storey group the Δ% becomes 27%. Meanwhile, the 80% SC set shows the other way around; higher building increased the overall Δ% within each group, albeit not as drastic as the 20% SC set.

Figure 12-14 displays the Δ% of envelope conduction, solar and fresh air intake gain respectively. Similar with the previous cooling load chart, type-1 for each group acted as the reference for the other 11 children scenarios within the same parent group.

Figure 12, the chart indicated that within the both 20% and 80 % SC set, the overall Δ% within each group gradually increases in parallel with height increment. The Δ% becomes notably high particularly in the most densely built set (80%-20st), where the Δ% between type 1 and 12 (the least compact urban layout) produced a 175% increase of envelope conduction gain.

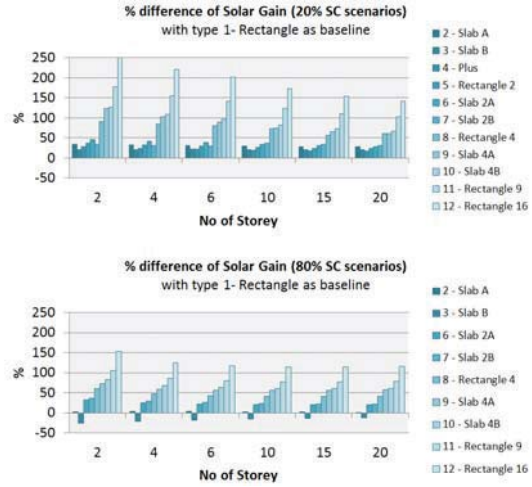


Figure 13 Solar gain chart for each parent group from both 20% and 80% SC sets.

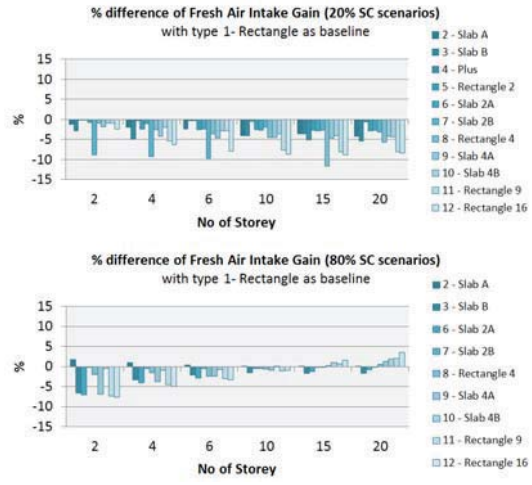


Figure 14 Fresh air intake gain chart for each parent group from both 20% and 80% SC sets.

Overall, varying the compactness of low office building heights (in this case 2-storey) could increase the conduction gain up to 40%; meanwhile in a denser neighbourhood (low SC and SVF, high buildings), buildings with more compact layout was preferable to minimize the conduction gain.

Figure 13 demonstrates that urban layouts with low SC required a proper strategy in order to mitigate the high solar radiation income. The chart shows that in 2-storey office blocks scenario, the least compact layout had 250% difference of solar gain when was compared to the reference type. This was mainly because in an open urban area comprised low height buildings, most of the surfaces were fully exposed to solar radiation, with no chance of self-shadowing. This explains why a less compact building (more surface area), ended up receiving more solar heat gain compared to a more compact one of the same volume.

Meanwhile, in 80% SC set, the solar gain Δ% typically were almost the same for any given building height group, except for the 80%-2st group, where the Δ% was slightly higher. This means if an office buildings master plan has tight street corridors (low SVF and high SC), it is expected to see a 20%-120% solar gain increase for any building form and height variant.

Figure 14 shows the fresh air intake Δ% chart. However, the trend was not as clear as the other two heat gain components. For 20% SC set, the trend seemed to show that in higher building groups, the lesser compact layouts lowered the fresh air intake gain. Overall, varying building form and height could bring Δ% up to 10%. This means fresh air intake gain was not dependent to compactness, but most likely related to outdoor ambient temperature.

Correlation with Urban Parameters

Figure 15 to 18 display scatterplots of cooling load result and its three external heat load components; in which they were correlated with urban parameters mentioned in the previous section (FAR, compactness, SVF, and SkyEF). The purpose was to look the impact scale of different geometry factors on the external heat load. For this purpose, all the load data was normalized into load per floor area (W/m^2).

Figure 15 displays compactness parameter had a good agreement with the cooling load (R^2 value of 0.83); while both FAR and SVF (R^2 value of 0.43 and 0.4063 respectively) have a decent relationship with the cooling load result. While these three parameters showed there was a good linear relationship, SkyEF parameters indicated a very weak correlation.

Figure 16 displays the scatterplots of envelope conduction gain correlated with urban parameters. It showed that compactness again had a strong correlation with conduction gain (R^2 value of 0.87), which suggested that compact buildings had lesser conduction heat gain. This indication was revealed in the previous Δ% conduction gain chart. Meanwhile, FAR and SVF showed a positive correlation with conduction gain, albeit not a strong one. SkyEF once again does not correlate well with conduction gain.

Figure 17 shows that only compactness parameter had substantially positive correlation and good relationship (R^2 value of 0.76) with solar heat gain. This indicated that compact buildings, which had received lesser exposure from the sun, generally had lower solar gain per floor area. Surprisingly, both SVF and SkyEF parameter showed a weak correlation to solar gain received by the building envelope; particularly when these two factors were supposed to be good quantifiers of sky openness and self-shading effect.

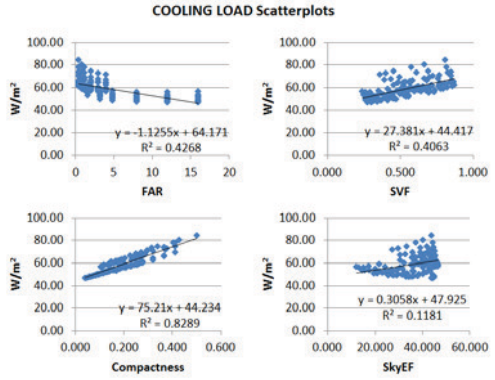


Figure 15 Cooling load correlation with urban parameters

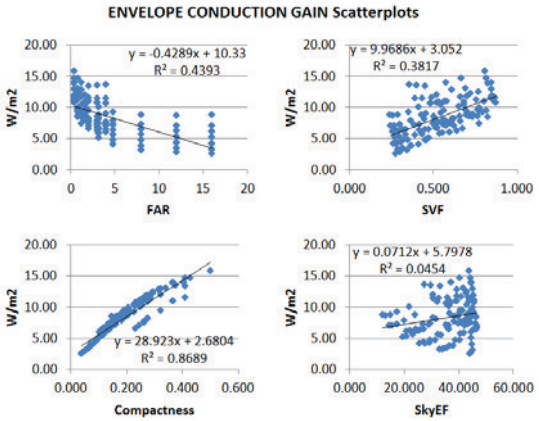


Figure 16 Envelope conduction heat gain correlation with urban parameters

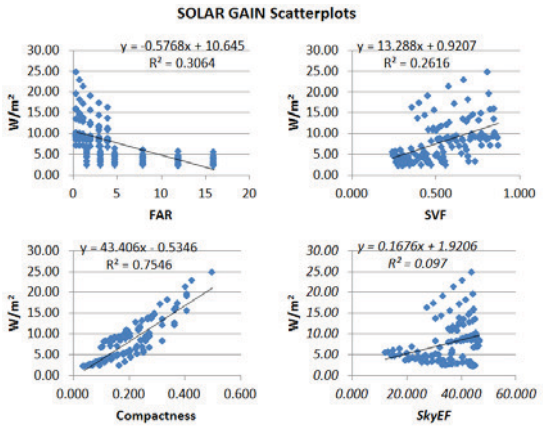


Figure 17 Solar gain correlation with urban parameters

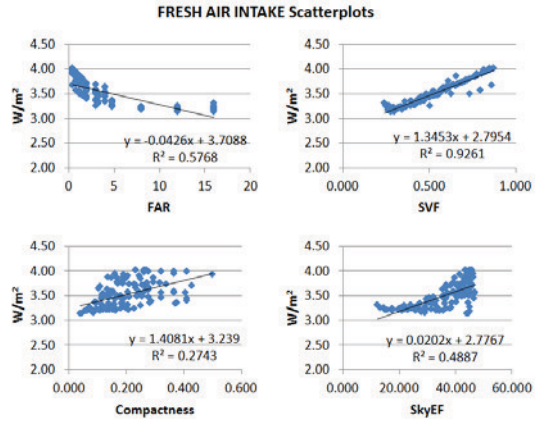


Figure 18 Fresh air intake gain correlation with urban parameters

Figure 18 shows different urban layout resulted in variation of fresh air intake gain. The scatterplots clearly displayed that SVF had substantially good agreement with fresh air intake gain, yielding an R^2 of 0.76. Positive correlation suggested higher SVF led to higher outdoor temperature, resulting in higher air intake gain and vice versa. However, this phenomenon contradicted the study on SVF where building with close proximity to its neighbours creates a narrow urban canyon, which may trap the heat to be released during the night; hence, causing the increase of temperature and creating the UHI.

DISCUSSION

It is important to note that the current results only represent the minimum and maximum scenarios (20% and 80% site coverage). In spite the incomplete simulation data, some preliminary results showed interesting findings.

It appears that average building compactness of a certain urban area can be a good measure to predict external heat gain received by the buildings envelope, except for the fresh air intake gain. An office block with low surface/volume ratio leads to lesser surface area exposed to the outdoor environment, particularly the solar radiation. On the other hand, the expected parameters SVF and SkyEF fail to provide good correlation with the heat gains. The preliminary results indicate these two parameters only correlate well with the fresh air intake gain, and yet this finding is still debatable.

Site coverage parameter is still out of the picture because the 30%-70% scenario sets have not yet been simulated. Only after the data set is complete, more statistical tests can be conducted to see significance of the urban parameters on affecting both cooling and external heat loads.

Another alternative analysing approach is to split the data into day and nighttime, rather using the whole day simulation output. This is because the scope of the study is using an office function, which the occupancy level is high during the day, and no activity during the night (the air condition is off and internal heat gain are assumed to be none). It is most likely with this approach that the data will represent a proper energy usage during the day, which can be correlated with the urban parameters. This will be a consideration for the future works.

CONCLUSION

The preliminary results and discussion indicate that by adjusting parameters on certain urban area, both architects and planners could be well informed on the how their design affects the external heat gains received by the buildings, and eventually the energy consumption. However, conclusive findings are still limited since this is still an on-going research. The remaining scenarios need to be simulated, in order to complete the whole data set. In addition, it is still possible to use other indicators, which may further explain the relationship between urban form and energy performance.

In spite the limitation, this paper has illustrated the importance on assessing urban characteristic with climatic data for better planning (from macro to micro level). In addition, the study also highlights the importance of conducting preliminary study of certain urban fabrics, especially for architects and urban planners to explore different options and foresee the design impact on outdoor temperature, solar gain, and energy consumption. The benefits of having a preliminary study done early (before the detail design process), is to tackle some issues in the early phase and not to mention saving time needed for detail building simulation at later stages.

On the other hand, the major challenge is to incorporate this micro-climatic analysis into real planning practice. Apart from the lack of climatic

knowledge within the industry, some urban parameters such as compactness and SVF are not common references among the planners. In order to bridge the gap between researchers and practitioners, an implementation of GIS could benefit both sides, as has been shown in previous studies by the authors. GIS has the ability to superimpose layers of information into the urban plan, and in this case, information on ambient temperature and heat load from certain urban fabrics could be presented graphically.

NOMENCLATURE

FAR	:	Floor area ratio
FIS	:	Geographic Information System
IES	:	Integrated Environmental Solutions
R^2	:	R squared value, coefficient of determination
SC	:	Site Coverage
SkyEF	:	Sky exposure factor
STEVE	:	Screening Tool for Estate Environment and Evaluation
SVF	:	Sky view factor
UHI	:	Urban Heat Island
Δ%	:	Percentage difference

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SEARCHING WAYS OF ACCELERATING THE NECESSARY CHANGES IN THE PRODUCTION PROCESS OF THE BUILT ENVIRONMENT FOR A SUSTAINABLE FUTURE

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ABSTRACT

This paper has the goal of presenting the main characteristics and challenges of the process of developing and disseminating solutions which aim to minimize the environmental impacts and improve the environmental performance of the CIPC in the mid-west region of Brazil. Over the past eight years many applied research projects have shown that the bottleneck slowing or preventing the evolution of CIPC in Brazil is the lack of political will, be it at the municipality, state or federal level and a desintegrated agenda. Exacerbated political interests added to a lack of capacity for integrated and efficient management of available resources and programs implementation curtail the continued and integrated technological development and as consequence it has delayed the effective evolution towards sustainable technological paradigms. With no political will, the steps toward change are slow, inefficient and dispersed, as demonstrated by an analysis of the development, implementation and diffusion of four projects which focus on the sustainability of processes and products of the built environment.

INTRODUCTION

The current technological paradigm in the Construction Industry Productive Chain (CIPC) which is responsible for the production of the built environment in Brazil still embraces a logic which insists on ignoring its environmental impacts.

Among the main innovation enhancing factors highlighted by the innovation theory, it can be mentioned the strengthening of the learning system of different agents acting in the CIPC, enabling absorption and evolution of technological paradigms.

The strengthening of the learning systems is a function of the interconnection of agents, actions and instruments, which allows for synergetic integration of responsibilities, expertise, solutions and resources, which must be shared among the public, private and third sector and the academy. This paper has the goal of presenting the main characteristics and challenges of the process of developing and disseminating solutions which aim to minimize the environmental impacts and improve the environmental performance of the CIPC in the mid-west region of Brazil. When structuring applied research projects few criteria are required: the agents involved must have complementary and synergetic goals; it is necessary a well-structured and coordinated process, continuous feedbacks in order to allow adjustments and a well-defined strategy focusing on the continuity and evolution of the installed process.

Over the past eight years many applied research projects which have been coordinated by the Lacis/UnB (Laboratory for the Built Environment, Inclusion and Sustainability of the University of Brasilia) have shown that among the bottlenecks which slow or prevent the evolution of CIPC in Brazil, it can be mentioned the lack of political will, be it at the municipality, state or federal level, revealed by an disintegrated agenda among government institutions and levels.

In the last decade, CIPC in Brazil has expanded greatly due to favorable economic conditions, government programs, such as housing and infrastructures programs and big international events programed to take place in the near future.

This scenario has created great opportunities of absorption of sustainable technological paradigms. Nevertheless, exacerbated political interests added to a lack of capacity for integrated and efficient management of available resources and programs implementation curtail the continued and integrated technological development and as consequence it has delayed the effective and fast evolution towards sustainable technological paradigms.

With no political will, the steps toward changes are slow, inefficient and dispersed, as demonstrated by an analysis of the development, implementation and diffusion of four projects which focus on the sustainability of processes and products of the built environment: Construction Waste Management Program (2003), Center for Studies and Research in Sustainable Penal Facilities (2007), the Solid Waste Observatory (2007) and the Park for Innovation and Sustainability of the Built Environment(2010).

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SIMULATION

The application of the principles of innovation and systems theory in the development and testing of methodologies which can accelerate paradigms shifts allows advances in the structure analysis aimed at strengthening of the learning systems of organizations (Blumenschein, 2004). These advances lead to extend the lens of analysis focused on the concept of innovation and identification of vectors which can influence their emergence and evolution.

Johnson (2010) offers an approach that emphasizes the complexity of the interconnection of the vectors that influence the emergence of innovations and in his analogy using the coral bank scenario confirms the importance of collaborative networks.

The ability to survive of coral reefs, is not a result of the survival of the fittest, but the ability to reinvent solutions from the results of exchanges and interactions that allow the discovery of new ways of survival. This is the definitive explanation of the paradox of Darwin: "The coral reefs found many ways of survival because of the way they share" (Johnson 2010:245).

By applying this analogy to the context of learning organizations resources, expertise and responsibilities sharing and integration can be considered as a major factor for the innovation process.

From this perspective, the central premise underlying the proposed analysis presented in this paper is that human organizations are in many respects analogous to living organisms and the application of certain metaphors help in understanding the problems faced by their solution. Organizations are systems of relationships and are embedded in a broader system defined by its external relations.

According to research carried out in Lacis, about innovation in the CIPC, the performance of a system of organizations is a function of integration and alignment among agents, actions and instruments. The goal of the method is to map the stakeholders in order to identify their actions and define their level of alignment and integration.

The method of analysis presented in this paper is part of the innovation models studies which has been developed by Blumenschein (2004). The establishment of the necessary network, which can allow the required integration of agents, actions and instruments demands the identification of the relevant elements to compose the adequate environment for the development of projects which aim to introduce innovations. Among the main elements it can be mentioned: legal or operational institutional instruments; compatibilization of institutional values and objectives of the participants' institutions; compatibilization of resources and responsibilities; and the research of methodologies and technologies which can be absorbed by the participants' institutions.

Therefore, the method used for the proposed analysis has considered three main steps:

1. The identification of agents, actions and instruments involved in the development, implementation and diffusion considering the network proposed for each project;
2. The structure of the process for the development, implementation and diffusion;
3. The identification of the main bottlenecks in each phase of each project.

ANALYSIS

A brief description of each project and respective objectives are presented hereafter, before presenting the agents, actions and relevant instruments for the development, implementation and diffusion of the projects which are objects of analysis in this paper. The main bottlenecks for the diffusion or continuity of the projects are also identified.

Building Site Solid Waste Management Program (PGM)

The Program for Construction Waste Management is part of the Material Management Program (MMP) which is a result of a partnership with Lacis/UnB, the Syndicate of the Construction Industry in Brasilia (Sinduscon-DF), the Syndicate of the Construction Industry in Goiania (Sinduscon-GO); the Brazilian Chamber of Construction Industry (CBIC); Furnas Central Electric Laboratories; and the Goiania's Municipal Government and the Government of the Federal District. The aim of MMP is to contribute to the management of the materials used in the construction process, in order to minimize environmental impacts from the extraction of raw materials to waste disposal.

The Program for Construction Waste Management aims to prepare the private and public agents to attend legislations and sustainable certifications. In construction sites it focuses on the responsibilities of constructions site managers and generators of solid waste from construction and demolition. In relation to the public sector it aims to design, develop and implement methodology for the definition of guidelines and guiding principles for the development of Municipalities Planning for

Construction Waste Management; and to develop technologies which demonstrate technical feasibility of the recycled construction aggregates.

Table 1
Building Site Solid Waste Management Program (PGM)

DEVELOPMENT/ IMPLEMENTATION	
Agents	**Responsibilities**
Lacis/UnB	General and technical coordination.
Sinduscon/DF; Sinduscon/GO	Interlocution with the local construction sector; Institutional and operational support.
CBIC	Interlocution with the national construction sector, and the federal public sector; Institutional and operational support.
Municipality	Definition of a place to install recycling plant; Elaboration of Municipal Planning for Construction Waste Management; Application of the construction recyclable aggregate a pilot testing project.
Furnas Central Electric Laboratories	Research and test of the construction waste recycling.
Actions	
Project and planning development Research Project for the development of the construction waste technology recycling Definition of the project management group	
Main Instruments	
Legislation which establishes the obligation, for constructors firms and municipalities, of the recycling of construction waste. Project Research and Planning Cooperation agreement among the participant institutions Meetings reports Technical reports	
DIFUSION	
Agents	**Responsibilities**
Lacis/UnB	Technical and scientific publications Capacitation program for construction firms
Sinduscon/DF; Sinduscon/GO	Dissemination among the construction firms through technical events and media in general
CBIC	Dissemination among the construction firms through technical events and media in general
Municipality	The implementation of the a recycling program
MAIN BOTTLENECKS	
The Municipality from Goiania assumed all the responsibilities of implementing the project and worked hard in order to assure its implementation. As the elections came and the party which won the elections was a different from the one which had signed the agreement cooperation the project was aborted by the municipality new government. The Government from the Federal District never assumed his responsibility with the project.	

Center for Studies and Research in Sustainable Penal Facilities (NUESP)

The Nuesp aims to work in the construction of information that supports the development of the productive chain of penal buildings. Created and implanted as a research project, it is dedicated to the study and development of research on the productive chain of penal buildings focusing on quality, rationalization and sustainability of processes and products.

It has been a project which was supposed to receive financial and institutional support from the Brazilian Ministry of Justice (BMJ). After all the negotiations and the project detailing the BJM has decided that the project has n o importance for their agenda.

Lately it has been integrated to the researches at the post-graduation course, at the Architecture Faculty of UnB, with the graduation course allowing the development of solutions and innovative penal building projects.

Table 2
Center for Studies and Research in Sustainable Penal Facilities (NUESP)

DEVELOPMENT/ IMPLEMENTATION	
Agents	**Responsibilities**
Lacis/UnB	General and technical coordination.
DEPEN – National Department of	Interlocution with the local construction sector; Institutional and operational support.
Actions	
Research Project development and planning including the follow aims: Criminal Architecture - Projects Proposals Evaluation of Existing Standards Penal Facilities - Theoretical Basis Standard for sustainable penal facilities. The design and implementation of a National Forum on Prisons in Brazil. National Conceptual Contest National for Penal Facilities. Constructional Materials Basket for prisons. Library Collection on penal criminal architecture.	
Main Instruments	
Project Research and Planning. Cooperation agreement among the participant institutions, nevertheless, although it had been agreed it was never signed.	
MAIN BOTTLENECKS	
Although the Ministry of Justice has agreed and participated of the development of the project research, and of the cooperation agreement proposal it has never finalized the negotiation process during four years.	

Solid Waste Observatory

The Solid Waste Observatory was developed by the (Lacis/FAU/CDS/FGA-UNB) with the financial support from the Secretary of Science and Technology for Social Inclusion from the Brazilian Ministry of Science, Technology and Innovation (MCTI). The Observatory is a knowledge management tool of recyclable and recycled waste, including information gathering, processing, storage, formatting (in various formats graphics, website, thematic geographical maps, tabular, textual reports, cross information from various sources, etc.) and dissemination.

The Observatory allows quick access to relevant and effective knowledge and aims to structure the information about recyclable solid waste management, integrating them into a single place, strengthening the knowledge on the subject and using a tool to store, retrieve, integrate, manipulate, analyze, and mainly involve spatial data to a database text and satellite images, allowing georeferencing technology, information and knowledge management.

Table 4
Solid Waste Laboratory

DEVELOPMENT/ IMPLEMENTATION	
Agents	**Responsibilities**
Lacis/UnB	General and technical coordination.
MCTI	Financial resources for the development of the project.
Actions	
Project and planning development Research Project for the development of the construction waste technology recycling Definition of the project management group	

Main Instruments	
Project Research and Planning. Meetings reports Technical reports	
DIFUSION	
Agents	**Responsibilities**
Lacis/UnB	Technical and scientific publications. Capacitation program for waste pickers cooperatives. Presentation to public and private institutions.
MAIN BOTTLENECKS	
The Government although financing the project does not participate in its diffusion using its influence power. There is a disintegrated government agenda. The public sector institutions are not prepared to publish its data and information, due to disorganization or due to cultural resistance. The expansion of the tool has not been possible due to the resistance of private and public agents who does not want their data published due to a misunderstanding of the real objectives of the proposed tool.	

Park for Innovation and Sustainability of the Built Environment (PISAC)

The Park for Innovation and Sustainable Built Environment (PISAC) is the result of a partnership with public and private agents in Brazil and the UK, involving the Building Research Establishment (BRE-UK), the Brazilian Ministry of Science, Technology and Innovation (MCTI), the Brazilian Chamber of Construction Industry (CBIC) and the University of Brasilia (UNB), through Lacis.

Based on the model developed by the Building Research Establishment (BRE) the PISAC is a research platform that integrates the productive sector, where the industry itself, collectively, can invest in science, research and development, accelerating the process of evolution of the CIPC.

This model also amplifies the impact of public investment and offers the opportunity to strengthen the alignment of government policies, goals, programs and actions.

The PISAC is an institution with the mission of fostering technological innovation, high performance, low cost and sustainable, meeting the current and future demands faced by the construction sector in Brazil, through:

1. Establishing network integration of national and international research and technological development of products from a specific demand of the private or public sector;

3. Meeting the needs of the construction sector of tests and inspections;

4. Testing and certifying material and products of the construction industry;

5. Offering consultancies;

6. Building capacity, training and technical events;

7. Publishing results;

8. Creating a platform for the development, management, integration and dissemination of knowledge, composed and supported by a set of tools and actions, and linked to a virtual platform for innovation parks for the Built Environment of the BRE, oriented to enhance the creation of generation networks, sharing and dissemination of research for the Supply Chain of the Construction Industry.

Table03

Park for Innovation and Sustainability of the Built Environment (PISAC)

DEVELOPMENT/ IMPLEMENTATION	
Agents	**Responsibilities**
UnB through Lacis/UnB	Liberation of a plot of land to install the project. General and technical coordination. Indication of researches that will coordinate and lead the project. Integration of political institutions into the project.

BRE/UK	General and technical coordination. Provide the model for the park operation. Integration of English political institutions into the project. Integration of the productive construction English sector into the project. Provide technology and methodology for the development of the project as a whole. Integration of Pisac to the network of BRE innovation parks.
CBIC	Integration of political institutions into the project. Institutional and operational support.
MCTI	Liberation of investment funds to seed the availability of the project. Integration of political institutions into the project. Integration of the productive construction Brazilian sector into the project.
Actions	
Project and planning development. Definition of the project management group. Dissemination of the project among the various government levels and construction sector in order to obtain financial support.	
Main Instruments	
Project Research and Planning Report. Signature of the cooperation agreement among the participant institutions. Meetings reports.	
MAIN BOTTLENECKS	
The disintegrated agenda among government institutions. The bureaucratic process of the public institutions. The lack of consciousness of the construction productive sector of the importance of the project and resistance to invest on it.	

CONCLUSION

Among the main drivers to the emergence of innovation it can be mentioned the establishments of networks which allow the exchange of resources including human, technical, financial and political.

The institutional arrangements are important tools for structuring the network as they act as support to ensure its full development, and it is important that they are used as instruments of documentation made through work plans, including: objectives, goals, responsibilities, resources, products, and schedules.

What is agreed must be formalized by means of agreements or Technical Cooperation Agreements, where each institution contributes fulfilling a function. The process is documented using the Reports of Meetings, which are the minutes that record the actions, results, placements and are essential tools in monitoring the evolutions of the projects' steps. The process of survival of the network depends on this structure.

The success of network survival depends on the meanings that come to permeate all levels, and operates as a guideline in the process of interaction of the constituent parts of the network. These meanings have their roots in the beliefs, goals, values, and needs of the institutions and their professionals.

The pilot projects have identified some factors and requirements to be met by similar experiences, so they can have more chances to success:

1. The potential of partnerships as a means of facilitating the operation of complex social systems

and organizational networks composing with specific goals;

2. The ability and efficiency of the network to save application resources and distribute channeled efforts to strengthen the achievement of goals;

3. The importance of consolidating meanings common to the network agents;

4. The strength of the legal instruments that push behavior change;

5. The role of the media in the dissemination and monitoring results;

6. The importance of providing practical methodologies for introducing new paradigms allowing speed changes;

7. The recognition of the political-institutional dimension as a critical point to achieve sustainability.

The results obtained with the development and implementation of the pilot projects presented in this paper show that all participating institutions consolidated results within their internal processes, strengthening their knowledge and learning processes which, according to Dosi (1988), is the main requirement for the processes of change that can be put into motion.

The change process therefore requires an analytical method that allows not only understanding the interdependence of all the changes, but at the same time unifying the factors that influence this process by influencing their footsteps and their direction.

Once these forces have been identified, it is necessary to exercise them in practice establishing references and strengthening the learning process so that more learning can take place in a continuous movement of natural evolution, always looking for improvements.

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LIVEABLE LANDSCAPE IN HIGH-RISE AND HIGH-DENSITY BUILT ENVIRONMENT FOR HEALTH PROMOTION IN SINGAPORE

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ABSTRACT

In recent years, liveable landscape design for high-rise has been introduced as an antidote to elevate the significance and value of living environment in high-density urban developments. Liveable landscape could be designed together with buildings because architecture as an applied ecology (Yeang, 1999) challenges urban constructions to integrate with natural systems in a sustainable way.

New theories, such as green urbanism is proposed as an anchor which defines interdisciplinary design pedagogy to shape sustainable places, communities and lifestyles (Beatley, 2000). Furthermore, the feature of liveable landscape looks beyond the physiological parameters of health and comfort and includes the psychological well-being of people and communities as well.

In this paper, the author uses Singapore as an example to explore three main aspects of liveable landscape as a healing place for people who live in the "concrete jungle", victims of green space scarcity; and discusses the potential of liveable landscape implement for other ultra-density urbanism such as Hong Kong's.

KEY WORDS

Liveable Landscape, high-rise, high-density, health promotion, Singapore

INTRODUCTION AND BACKGROUND

Each day, the population on the planet is growing rapidly while natural resources and land supply in our world is declining. The concept of sustainable development as defined by *Our Common Future* is: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.'(WCED, 1987) Based on the principle, maximizing land worth and minimizing resource waste become key issues in the process of human sustainable development.

After World War II, accompanied by booming economic development and infrastructural expansion, huge numbers of people flocked into cities, and sparked a fast urbanization all over the world, especially those developing countries. More than half a century past, there are already 21 cities with populations of more than 10 million in 2010[1], and 10 of them located in Southeast Asia. Confronted by severe land shortage and high population pressure, some cities adopted compact urban form with extremely high dense and high rise building morphology, i.e., Hong Kong and Singapore. The generalities of the cities in Southeast Asia show, as tropical and subtropical climates, ultra high-density urban form and rapid economic growth.

Recently, triggered by climate change and environmental degradation, liveable landscape system for high-rise morphology has been introduced as an antidote to elevate the significance and value of living environment in high-density urban context. The scope of "high-rise landscape" refers to the man-made ecological system of outdoor and indoor environment, including green roof, sky garden, podium parks and vertical greenery etc., which integrates natural ecosystem with buildings and urban infrastructure. From this point of view, the designed system must create a balanced ecosystem of biotic and abiotic components and a productive and even reparative (i.e., healing) relationship with natural environment (Yeang, 1999, p68).

RESEARCH REVIEW

Environmental Sustainable Philosophy

(1) Design with Nature

Although there is a wealth of literature exploring the philosophy between design and nature, the most authoritative originator comes from the forerunner of modern urban planning and design Ian L. McHarg 's immortal book, *Design with Nature* (1971). It reshaped the modern design theory towards a relationship of nature and man, and elaborated the methodology and vision to future ecological city. After city expansion in the early 20th century, the vast countryside was encroached by urban industrial production in the western world. McHarg argued that the loss of western urban civilization was caused by popular values: human power is the only master of the world and nature is just the weak background of human activity (McHarg, 1971). However, just as Hippocrates once said: 'human life, whether sick or healthy, are closely related to the natural forces, and nature is irresistible and invincible, we must understand its laws, to respect its advice, and treat it as an ally' (Mumford and Rui, 1995).

From historical culture to religion, the eastern vision considers that if man and nature could live in harmony, the world could be kept in balance. In ancient China, people understood how to deal with the deluge and make a self-sufficient life in a sustainable

1 Source: United Nations.
http://www.un.org/esa/population/unpop.htm

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way, which is the so-called "the art of survival" (Yu and Padua, 2006). Since natural sources will be used up and our future generation will lose their equity caused by the unsustainable lifestyle we once behaved, design with nature becomes the lifesaving approach to build a bio-diverse natural ecosystem and make a connection between city and nature. The philosophy in the large vision combined regional planning and landscape architecture together to deal with the problem in the process of urban expansion and nature conservation (Li, 2005).

(2) Green Urbanism

After the energy crisis erupted in the 1970s, the western world was shocked by the huge amounts of oil consumption and the natural resources scarcity simultaneously. New theories, such as green urbanism is being proposed as an anchor of the future vision of sustainable construction. It is an interdisciplinary design pedagogy that combines the collaboration of landscape architects, urban planners, engineers, ecologists, transport planners, sociologists, economists, physicists and psychologists in addition to that of architects and urban designers, to shape sustainable places, communities and lifestyles (Beatley, 2000). Green urbanism encompasses the ecological functions of urban greenery which has a positive impact on the performance of building through its whole life-circle.

The theory of green urbanism truly supports that cities are fundamentally embedded in a natural environment, and they will behave like an ecosystem network with the function of metabolism (Beatley, 2012). When William McDonough argued that "buildings like trees, cities like forests" (Beatley, 2009), it could be deduced that buildings and cities will be not linear systems which just consumes energy and products and produces waste and pollution. Actually, a healthy urban system will have ecological cycle, with green network between cities and buildings. New approaches, such as green roofs, green walls, green streets and neighbourhood, city farms and urban gardens will remodel the built environment with organic, living buildings and urban landscapes.

(3) Green Skyscraper

In the early 1960s, early study of "Metabolism" architecture argued that the way to develop a city is the continuous renewal and organic growth, and architecture with limited land will be regeneration in a biological approach. At the end of the 20th century, well known avant-garde green eco-architect, Ken Yeang proposed that green and ecological skyscrapers could be the main force for the future urban construction (Yeang, 1999). Since architecture as an applied ecology challenges urban constructions to integrate with natural systems in a sustainable way, eco-architecture such as "Vertical Urban Design", starts a new high-rise typology: City in the Sky. In Yeang's research, urban greenery could be shifted from the ground to the podium and rooftop in a high-rise buildings and skyscrapers, which largely improved the efficiency of land use and promoted the multiple diversity of community life. Just like Yeang's vision, where there is symbiotic relationship between manmade system (building) and the ecosystem (landscape), in order to create 'building-as-landscape' and 'landscape-as-building' (Yeang, 1999, P89).

Ken Yeang adopts natural greenery as an organic air conditioning system, which aims to produce additional oxygen, sun-shade and performs as a microclimate producer (Ruby, 1999). Meanwhile, studies on vertical greenery systems in Singapore by scholars from NUS have made credible up-to-date information and findings of the benefits and concerns of vertical greenery system in the built up urban environment (Wong et al., 2010).

Compact City and Intensive Land Use

Over the last decades, the majority of urbanists, architects and territorial planners regard the compact city as the most sustainable settlement typology of urban development theory to deal with the continuous broadening of modern urbanization. However, according to previous case studies, it depends on the environmental, social and economic context, and defers from the developed world and the developing countries. In our topic, the main problem of the compact city theory is the lesser green and open spaces than could be obtained in a dispersed city (Holden and Norland, 2005). Actually, compact city can be very large and function well under elaborate planning and organization, which requires compatible management at the governmental level, i.e., Singapore (Gugger and Kerschbaumer, 2013), who favors promoting community greening amid a high density built environment.

Since land and resources are limited, only an intensive land use in urban context could address the needs of huge populations, especially in Asian countries (Lau et al., 2003). The 20th century was a century of skyscrapers (Ali, 2006). Based on the social, political, cultural and economic reasons, mega-structures become the normal habitus in the megalopolis all over the world. Yet, previous studies have prejudiced towards the skyscraper and other large buildings for the negative effects to our ecological environment, since they are energy-hungry parasites (Yeang, 1999) because of their huge size. Actually, high-rise or skyscraper is not an architect's personal favourite, but a coping strategy to deal with the serious problem of swift and accelerated urbanization. Yeang's attempt is to interrupt the omnipresence of architecture with botanical oases (Ruby, 1999) and these oases located at the sky scrapers morphologically appeared as sky gardens, the podium parks, the green walls, etc., which constitute a great compensation for the scarce of open space and greenery in the context of high density built environment.

Environmental Therapy

(1) Environmental Psychology in Urban Context

According to the Master Robert Gifford's definition, Environmental psychology (EP) is the study of transactions between individuals and their physical setting (Gifford, 1997). Simply, EP is a study of man as part of his milieu. It sees man not as a passive product of his environment, but as a goal-directed being who acts upon his environment and who in turn is influenced by it (Ittelson, 1974). For instance, good lighting promotes better learning in schools, green open space reduces pressure from work, etc.

In addition, EP serves as a key link between individuals and policymakers (Gifford, 2007). According to the policy making, individual's behaviour, well-being, stress and quality of life could be changed. Our question is how to make a city liveable? To be focused on the environmental study, a liveable city should have the characteristic of aesthetic and stimulus qualities which encourages people to live in the city (Ittelson, 1974). Cities as the built environment change the style of urban life through changing the urban form. From the traditional courtyard house and street market to the skyscraper and high-rise apartment, the living habits of millions of people has changed by the fast urbanization, and in turn, new demands has raised along with the changes in the environment. The lack of natural space becomes a huge shortage in modern city, since a positive distraction of natural environment could improve emotional state and block or reduce worries from the chaos around (Marcus and Barnes, 1999).

(2) Design and Health

The World Health Organization (WHO) defines '*Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'* (WHO, 1946). The emphasizing of mental health and social well-being raises a new concept, Salutogenesis, proposed in 1979 by medical sociology Aaron Antonovsky as the study of the relationship between health, stress, and coping. Different from the traditional vision of Pathogenesis, Salutogenesis works prospectively by considering how to create, enhance, and improve physical, mental, and social well-being (Becker et al., 2010), and guides the framework of health care system in the new era.

Previous research about Salutogenesis indicates that the environment (indoor and outdoor) plays an important role in affecting people's physical and mental health. The garden labeled as "healing" should have therapeutic or beneficial effects on the great majority of its users (Ulrich, 1999). The core capacity of healing landscapes would have fostered emotional well-being and health, and enhanced chances by promoting faster and more complete recovery from the negative stress and threats from surroundings (Ulrich, 1999). In this paper, the concept of healing is not focused on the health care place and patient regimen. Instead of that, the author would like to explore the healing places served to the residents, the office employees and others who live in the "concrete jungle" and suffer from the scarcity of the green space.

Summary of Research Review

The philosophy of sustainable development has a deep foundation in theory and practice of urban and architectural design since late 1960s. With the rapid increase of urbanism, compact city and intensive land use became the main stream in the process of urban development, especially in high-density Southeast Asian cities. Meanwhile, the ultra-compact and lack of greenery and open space in urban built environment has made a great impact on people's physical and mental health. According to previous research of environmental psychology and therapy, qualified natural resources which performed as urban oases in the forms of sky garden, green roof, vertical greenery and green terrace etc have increased living quality and human well-being. Since the perceived benefits of the integration of ecosystem and manmade system have been well studied in ecological, social and economic levels of high-rise and high density urban context, the author's interests will be focused on the non-material efficacy which liveable landscape brings to the individual and the community.

RESEARCH DESIGN: CASE STUDIES IN SINGAPORE

Framework

(1) Research scope and factors

From the analysis of figure 1, the 3 levels of ecosystems link together as a holistic recycled system. Since the urban built-up area has interaction effect with the suburban ecological environment, so does the buildings and infrastructures with the semi-ecological open space within the urban area. In the author's research, the liveable landscape integrated with the buildings especially high-rise and skyscrapers, behaves like a live ecological system to metabolize and communicate with the outside open space.

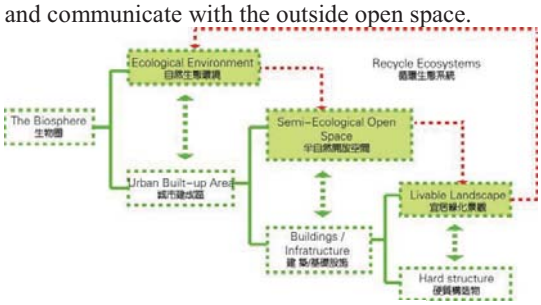


Figure 1 Research Scope

Since 2005, as defined in the publication of the Millennium Ecosystem Assessment (MEA), the main categories of ecosystem services is "provisioning, such as food and water; regulating, such as regulation of floods, drought, land degradation, and disease;

supporting, such as soil formation and nutrient recycling; and cultural, such as recreational spiritual, religious and other non-material benefits". Based on the principle of ecosystem services, the research factors of liveable landscape system will be focused on the context of high-rise and high-density urban context and the supported to the buildings and the communities.

According to the ecosystem services, the main factors of liveable landscape values in this research reveals the following: A. Environmental conservation: covers biodiversity promoting, rain water recycling, nutrient/waste recycling, food self-supporting, energy saving and micro-climate regulation; B. Healing therapy: covers spiritual enrichment, pressure reduction, cognitive development and aesthetic experiences; C. Community placemaking: covers recreation, education, neighbourhood identity and social interaction, volunteer action.

The author will focus on analyzing the above three key issues, and discuss the important value and the future trend based on the comparative case studies.

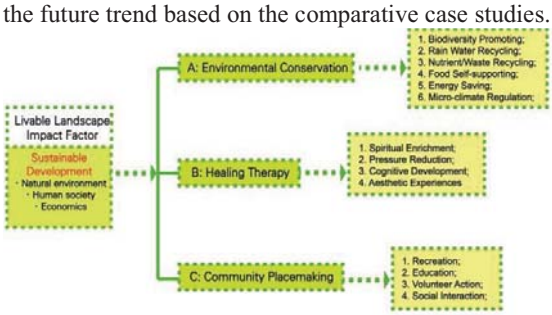


Figure 2 Research Factors

(2) Strategy analysis

The research strategy will mainly follow the logical deduction process. Firstly, is to identify the research object as liveable landscape in high-rise and high-density built up environment; Secondly, through previous research literature review, to find the theoretical basis of sustainable development in urban construction, compact city mixed intensive land use and environmental therapy in health promotion to support the research hypothesis; Thirdly, to choose three representative cases in Singapore as data sources, analyse the information, summarize the findings and discuss the advantages and shortcomings of the current status.

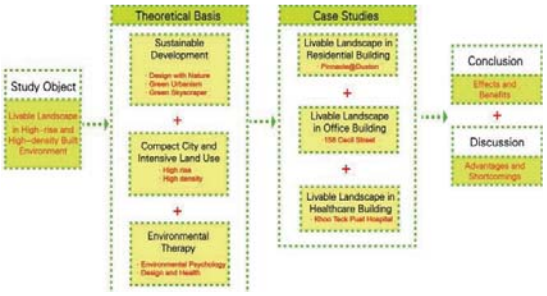


Figure 3 Research Framework

Case Studies

Three types of high-rise buildings with liveable landscape systems were chosen as case studies, including residential, office, and health care, and each case has unique characteristics and innovations. The information of case studies came from site studies, experts/architects interviews and internet resources. These cases are newly developed famous projects in recent years which establish an unprecedented height of green building design and management as well as the models for the future development.

Pinnacle@Duxton is an outstanding iconic housing project in the public housing history of Singapore. It has 115,415.58 m2 GFA with 7 high-rise towers and 1,848 apartments makes up of the community. 158 Cecil Street is a pioneer existing building addition and alteration ("A&A") project located at the traditional CBD of Singapore. An obsolete building was transformed into avant-garde building through façade renovation, and it became the highlight of the city centre. Khoo Teck Puat Hospital (KTPH) is an eye-catching program aimed to integrate various ecological resources to build a "hospital in a garden, and a garden in a hospital". (San, 2013) All of the three projects have a commonly spectacular character by integrating large-scaled liveable landscape systems into buildings and communities which provide green courtyard, podium garden, sky (roof) garden, and vertical greenery to everyday life. The three projects stand for living, working and health care, three key components of human society which covers the most part of everyday life.

Table 1 Basic information of three projects

Category	Pinnacle @ Duxton	158 Cecil Street	Khoo Teck Puat Hospital
Completed	2009	1984 (origin) / 2011 (retrofit)	2010
Project type	7-Tower residential community	Single office tower, existing building retrofitting	Three blocks healthcare center
Services type	Public house	Rent office	Public hospital
Key study factors and Unique feature	2 Layer of connected sky gardens Iconic housing project in Singapore's public housing history	Existing Building ("A&A") project Office retrofitting with a Hanging Garden in the Atrium	patient-friendly, environmenta-lly friendly and hassle-free hospital Healing Environment: hospital within a garden,
GFA	115,415.58 m^2	11,977.28 m^2	105,000 m^2
Stories	50	14	6, 8, 10
Cost	SGD 279 million	checking	SGD 490 million
Height	156 m	45 m	48/58 m
Greenery Area	1 hectare	37,000 sq feet (The latest A&A Part)	checking

(1) Environmental Conservation

After reviewing the three projects, Pinnacle@Duxton has a large green courtyard at the community centre, which conserves the original big trees out of ruining during construction; and 2 layers of continuous sky gardens weave through the seven tower blocks, which added almost 1 hectare of green land in the sky and is kept as a habitat for biodiversity. 158 Cecil Street has a fascinating turn by creating a "Hanging-Garden" in the concrete jungle of CBD. Benefit from the designer's innovative experiment, a vertical greening took place of the existing "mesh façade", and the end wall and columns turned into a hanging living garden (Kan, 2011). After the lush green atrium set up, birds and butterfly go there to nest and people and nature live in harmony. Khoo Teck Puat Hospital (KTPH) is a paragon of "design with nature". KTPH is actually a living habitat with more than 500 plants species and over 100 butterfly species (San, 2013). With the technique of rain water harvest and nutrient/waste recycling, KTPH has built an urban farm on the roof top to provide food self-support within the community ecosystem. All three project performed well in energy saving and micro-climate regulation by the artificial liveable landscape system which also supports the shading, fresh air provision and ecological balance for human beings.

Table 2 Environmental Conservation Analysis

Category	Pinnacl@ Duxton	158 Cecil Street	Khoo Teck Puat Hospital
Original plants protection	Yes. Protect the historical trees	N/A	N/A
Biodiversity promoting	Good. Birds / Insects	Good. Birds / Insects	Excellent. Birds / Fish / Insects
Pest Control and Prevention	N/A	Yes. Inorganic medium	Yes. Organic pesticides instead of chemicals
Rain water recycling	Checking	Yes Rain water for plants irrigation	Yes Yishun pond collect rain water and irrigate plants
Nutrient /waste recycling	N/A	N/A	Yes Leave and fruit harvest for the farming fertilizer
Food self-support	N/A	N/A	Yes Urban farming on the roof garden
Energy saving	Moderate. AC reduction	Good. AC reduction	Good. AC reduction
Micro-climate regulation	Yes. Heat island effect reduction	Yes. Heat island effect reduction and indoor air quality promoting	Yes. Heat island effect reduction and indoor air quality promoting
Sum	Good	Good	Excellent

(2) Healing Therapy

In the author's view, creating a healing environment dominates the design concept of the three projects. Pinnacle@Duxton is a showcase to improve the living condition of public house. Government made great efforts to build a modern green community in the neighbourhood not only to promote a material environment, but also to create a qualified spiritual home for people to enjoy healing therapy from the garden and nature. 158 Cecil Street is a miracle to turn the concrete jungle into a natural garden. The retrofitting of façade and atrium brings a new approach to integrate natural elements to the "cold place" to make the building alive. After that, the office building fosters a place identity and place dependence which has promoted the intimacy with people and nature and guides people to become biophilia. KTPH has made a cold and fearful hospital into a "hassle-free" garden. Healing and therapeutic green space by the powerful design of natural gardens has gained great success which becomes a premier hospital of the future, and a new approach for future lifestyle.

Table 3 Healing Therapy Analysis

Category	Pinnacl@ Duxton	158 Cecil Street	Khoo Teck Puat Hospital
Spiritual enrichment	Yes. Lead residents to join outdoor activities	Yes. Promote employees to enjoy the natural communicat ion space	Yes. Provide patients ,staff and visitors beautiful and vivifying natural environment
Pressure reduction	Yes. Sky gardens reduce the pressure by high density living condition	Yes. Green wall and atrium reduce the pressure by intensive working load	Yes. Natural courtyard, roof garden and vertical greenery relieve the stress from both mind and body
Cognitive development	Yes. Encourage residents to foster biophilic habit	Yes. Encourage employees to feel and love for nature	Yes. People understand the nature well by the biodiversity of KTPH
Aesthetic experiences	Yes. Beautiful view in the theme park on the roof top promote a pleasant mind	Yes. Hanging garden creates natural beauty	Yes. The wonderful courtyard and vertical greenery promote a nice mood for patients and staff
Sum	Good	Good	Excellent

(3) Community Placemaking

The most significant placemaking in the neighbourhood is to promote a healthy lifestyle to individuals and families. Including the residential, the office and the healthcare centre, three cases have made wonderful achievement by demonstrating how to lead a healthy life both physically and mentally. The placemaking in Pinnacle@Duxton opens a gallery

for visitors to experience the fantastic sky gardens with the city's skyline. The residents could enjoy the lush open space within their blocks and spend the family time with community activities. The huge success of the "hanging garden" in 158 Cecil Street made this humble building become a CBD icon. Without ornate decoration and high-tech stack, this office building has skilfully built an eco-bridge between the man-made world and the natural environment. The approach of placemaking changed the cold, boring and rigid work place into a vivifying, cheerful and creative human oriented space, which proves that liveable landscape system could transform the negative to positive successfully. Not to mention the KTPH, which is an integrated modern community centre including the function of healing, work, entertainment, popular science education and park for the nature lovers. The placemaking of the KTPH has changed the hospital from a fearful disease treatment place into a health-promoting park, which is called "hospital within a garden, garden within a hospital" (San, 2013).

Table 4 Community Placemaking Analysis

Category	Pinnacle@ Duxton	158 Cecil Street	Khoo Teck Puat Hospital
Open to public	Partly. The 50th storey sky gardens are open to the public while the 26th storey ones are not.	Case by case. Only an appointment with the property management before.	Yes. Besides the patients and stuff, visitors and residents in the neighborhood are welcome.
Recreation supporting	Yes. There are 12 theme sky parks function as recreation facilities for residents	Yes. There are benches and sky bridges for employees to chat and communicate under the green environment.	Yes. The gardens provide large theme park and lush green land for visitors and children to play with.
Education and cultivation	Yes. Visitors come to learn the wonderful approach of a large sky gardens above apartment.	Yes. Employees of the building learn to symbiosis with the ecosystem; visitors learn the approach to build a green office	Yes. Visitors learn to cognize biodiversity; designers learn how to build a healthcare center in a garden.
Neighborhood identity and social interaction	Yes. Residents communicate with each other through the garden placemaking	Yes. People near neighborhood come to visit the hanging garden and cherish the community environment	Yes. KTPH is more than a healthcare center, but a community park to attract people come and enjoy life here
Volunteer action	N/A	N/A	Yes. People from neighborhood voluntarily take care of the roof farm to experience the sustainable lifestyle
Sum	Good	Good	Excellent

Discussion

Singapore's successful experience in liveable landscape system has a significant influence on other compact Asian cities, i.e. Hong Kong. With the similar level of economic development, Hong Kong suffers from low urban eco environment in residential, work, healthcare and other urban public space. In recent years, government has recognized the importance of a healthy environment towards the future development and made relevant legal provisions to ameliorate the "concrete jungle" urban environment. With the binding of "liveable landscape" and "concrete jungle", the life quality will be largely promoted and the negative life style will be changed by the healing therapy of natural environment.

However, the concerns of roof load, subtropical plant chosen, system maintenance, financial subsidies, cost issues and professional support needs to be settled in the process of new policy promotion. With the government's policy guidance and civil society's advocates, the liveable landscape system will be located in every neighbourhood, the healing power will be transferred to the citizens and the love of nature will be fostered in this and future generations.

CONCLUSION

The multiple benefits of liveable landscape system has been adequately represented by three representative case studies in the ways of environmental conservation, healing therapy and community plancemaking. The liveable landscape integrated with high-rise and high density urban built environment could connect the city with the natural habitats, and largely cultivate the biophilic love of nature and wild life as below:

(1) Under the high-density and high-rise urban context, urban ecosystem could mitigate the negative effects of ecological and social crisis from compact city morphology through establishing liveable landscapes integration with buildings and infrastructures.

(2) Liveable landscape not only has a huge advantage in ecological benefits, but also plays a lead role in spiritual healing and social value promotion.

(3) Liveable landscape in high-rise residential communities where lack of urban open space in the compact city could be available to proximity to nature by building sky gardens, podium gardens and vertical greenery etc., which greatly improves the quality of life as well as happiness index.

(4) Liveable landscape in high-rise office buildings where people suffer from bad air quality and high pressure working load could largely improve the

work efficiency, reduce work pressure, and promote harmonious communication among colleagues.

(5) Liveable landscape in healthcare centre has a special contribution to relieve patients' physical and mental pain, reduces staff psychological stress, and provides amiable public open space for community members. The healing park could draw a big picture in promoting social well-being.

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Figure 4 Pinnacle@Duxton



Figure 5 158 Cecil Street



Figure 6 Khoo Teck Puat Hospital

WHAT IS A GREEN POLICY- AN ANATOMY OF GREEN POLICY THROUGH TWO ASIAN CITIES: HONG KONG AND SINGAPORE

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ABSTRACT

This paper, primarily based on an initial study of two dense cities in Asia – Singapore and Hong Kong, compares their performance in green building and argues that legal provisions play an essential role in promoting green building. These two cities present two respective models for mandatory and voluntary development. This paper first describes the criteria used to evaluate policy. Later, it introduces four categories - policy, program, implementation and evaluation which can be used in policy making and discusses respective values based on the criteria. Combined with the experiences in Singapore and Hong Kong, the paper represents different types of implementation scenarios. This paper concludes with an overview of effective approaches toward encouraging green building and provides suggestions for further study.

INTRODUCTION

Climate change and the energy crisis are the key drivers of policy and legislation (Adshead, 2011). Buildings consuming impressive amounts of energy are receiving increasing attention all around the world. Green building involving resource-efficient construction, renovation, operation, maintenance and demolition (USEPA, 2009) is regarded as an effective path leading to sustainability.

The benefits of green building are remarkable such as less impact to the natural environment, water saving and recycling, energy efficient facilities, efficient usage of material and systems and creating healthy indoor environmental quality (USEPA, 2009; USGBC, 2009). Many governments around the world are adopting policies to encourage green building and ensure building components and facility systems are green.

With growing interest in green building among national governments, local governments, international agencies and private organizations, the approaches available for policymakers to promote green building are diverse and varied. Voluntary and mandatory tools in legislation are the two major poles in policy scenarios. In developed countries, such as UK and Netherlands, voluntary measures are being used in regulations and have proven to be a big success in driving standards upward. While developing countries, on the other hand, depend on strong legislation to acquire the desired results – as reflected in Taiwan, an area that is gradually progressing to more mandatory policies (Adshead, 2011).

Although existing policies in different areas and countries have provided guidance in policy-making, the efficiency of how to motivate action toward green building has not been extensively explored (A. R. Pearce, DuBose, & Bosch, 2007). The likelihood of success will be potentially affected by different political and organizational contexts (A. R. Pearce, et al., 2007).

This paper, primarily based on an initial study of two dense cities in Asia – Singapore and Hong Kong, compares their performance in green building and argues that legal provisions play an essential role in promoting green building. As two respective models for mandatory and voluntary development, these two cities present distinct outcomes of the models: Singapore, covered by lush greenery, is regarded as a "city in the garden"; while Hong Kong is like a concrete jungle with scarce vegetation in the urban area. This paper first describes the criteria used to evaluate policy. Later, it introduces four categories (policy, program, implementation and evaluation) which can be used in policy making and discusses respective values based on the criteria. Combined with the experiences in Singapore and Hong Kong, the paper represents different types of implementation scenarios. This paper concludes with an overview of effective approaches toward encouraging green building and provides suggestions for further study.

CONSIDERATIONS OF GREEN BUILDING POLICY

The ultimate goal of conducting green building is to achieve sustainability, which provides a balanced composition in environmental, social and economic elements. These three aspects work together towards a stable and effective system, which can be a basis to evaluate and compare legal program design. Proposed by Munasinghe (Munasinghe, 1992a), the ideal

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framework of sustainability consists of three overlapping circles, each representing a different element: environmental, social and economic. However, in reality, economic considerations usually dominate the result, with fewer considerations to the social aspect. Environmental concerns always end up ranking last (Fig 1).

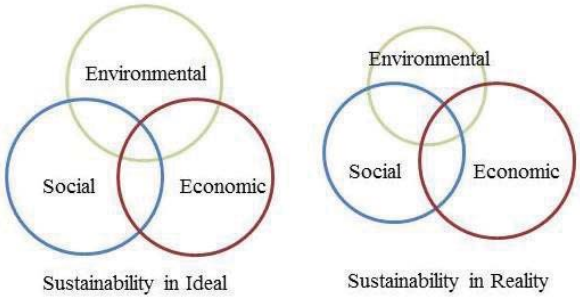


Fig 1Sustainability in Ideal & in Reality

Environmental Considerations

Buildings have a huge impact on energy consumption, the natural environment and the ecological system. The United Nations Environment Program recently reported that buildings use 30%-40% of all primary energy on a worldwide basis (Huovila, 2007). This number will increase by 10% if the energy required to make building materials and construction materials are included (Baum & Council, 2007). Building construction needs natural resources and creates a vast amount of waste. In addition, building operation consumes energy and produces environmental pollution. A complete accounting should consider the overall energy consumption in a building's life cycle, including building maintenance, demolition and disposal as well (Norris, 2001). For inefficient buildings, although the cost of energy usage will be paid by building owners and occupants, the greenhouse gas emission and waste from construction and demolition impose a long-term debt on future generations.

Buildings also account for storm water staggering in the city. The concrete surface of buildings blocks water penetration into the ground, leading to insufficient ground water supply (Del Percio, 2004). Indoor air quality is often worse than outdoor air, which threatens people's health by jeopardizing their respiratory system. The life cycle of buildings should be an opportunity instead of threat to people and future generations. The value of efficient and ecological building practices, which consume and dispose less, needs to be realized by policy makers, planners, developers, designers, builders, building owners and occupants.

Social Considerations

Political theory has long adopted the idea of sustainability – this generation should preserve resources for future generations. The contemporary sustainable movement promotes economic development in an ecologically friendly and socially responsible manner, addressing "important issues related to the inequitable allocation of the world's resources." (King & King, 2004) It hints that the process of sustainability will be slow, inconsistent and incomplete if sustainability depends on private business development. Experiences from private developers' practices show that profits are their primary concern. The cost of sustainability against economic benefits for individual projects is the perceived negative impact for implementing sustainable business practice (King & King, 2004). Accordingly, for the majority of aggressive developers, voluntarily embracing sustainable standards and internalizing huge environmental and social cost without any governmental support would remain an externality in their projects (Circo, 2008).

Potential social rewards of green building are mainly in the benefits of health and creating a green-collar industry (A. R. Pearce, et al., 2007). The improved indoor environmental quality increases facility occupants' living satisfaction and working effectiveness. Building with improved air quality, natural lighting, better circulated air conditioning and heat provide a more pleasant and healthy indoor space, resulting in a high quality life and a productive industry. The available savings from efficient facility operation and maintenance costs can be used to enhance other fields. The new industry of promoting and practicing green building opens a market for larger involvement.

Economic Considerations

Green building is perceived to not only save substantial operating energy (Broughton, 2006), but also to improve the indoor quality of buildings, increase occupants' productivity and create market value. A broad acceptance among private agencies confirms that various kinds of green labels serve as positive business recognition (Circo, 2008). The direct and indirect cost associated with green building policies and programs results in a better performance facility. Categories of program costs include (Bennett & James, 2000; A. Pearce, 2004):

- Cost of green building certification;
- Increased cost of additional design, construction requirements, nontraditional system, etc.
- Increased cost of operations and maintenance fee of the nontraditional system;
- Training cost;
- Technical support cost

However, green building cost does not necessarily increase substantially compared to normal projects. Experience from developers has revealed that processing green elements at an early stage do not bring much additional cost for projects (Lau & Greenpeace,

2011). The cost of green building projects also depends on green facilities incorporated into the building. Introducing passive design as a response to local climate and site condition into new buildings will not add significant extra cost. Solar panels or wind turbines are not good business products for urban buildings, due to their high cost, low energy contribution and long payback period. Typically green building will cost an extra 3-5% compared with a normal building, although this number may change due to various project types (Circo, 2008). These costs are associated with the risk of maintenance costs if the innovative green building technologies do not work as well as expected (A. R. Pearce, et al., 2007).

Even though the perception that green building adds a substantial cost is one of the main barriers to adopting green building strategy, cost analysis based on real project data, ranging of wide sustainable technologies and passive design solutions contrasts with this perception. Significant improvements in environmental performance can be realized by little additional cost. Green building makes economic sense in a life cycle basis, which provides a continuous evaluating system to calculate buildings' life cycle performance (Kibert, 2003). Of course, energy-saving lighting and air-conditioning systems with additional response to personal requirements and surrounding conditions will cost more than conventional counterparts. Cost-benefit analysis reveals that early investment of extra money in green building will pay back within in a relatively short time period. As energy and water prices rise, the payback time will be even shorter. The corresponding savings accumulate over the whole operation period.

Green building can technically offer sufficient operational savings, but the market is still not fully convinced due to a "lack of awareness about the benefits and opportunities of green building" ("Mayor Menino's Green Building Task Force Report Executive Summary," 2004; UnitedNationsEnvironmentProgramme, 2006). Since profit is the major concern of builders, their goal is not to keep the investment low, but to keep it as low as possible. The difference between the actors who are in charge of the operational phase and those who are involved in the construction process creates a conflict of interests and impedes the incorporation of energy-efficient facilities into green buildings. Builders seldom benefit from the long term savings because they expect to be out of project once it is completed. The other market role-players often do not have enough information on green building.

Together, environmental, social and economic considerations influence the practice of green building and form a holistic basis to evaluate policy-making strategies.

GREEN BUILDING POLICY OPTIONS

Policies and programs which can be incorporated into policy-making are studied and categorized into four options:

- Policy, a formal guidance executed by government officials, is to require or encourage green building activities;
- Programs, which provide support and resources to make green building easy to achieve;
- Implementation, guidance or technical support to meet the policy goals;
- Evaluation, which serves to measure or evaluate the success of green building projects.

Policy Options

Meet Certain Green Building Standards: A policy can mandate order to meet with a specific set of green building standards. Normally, different areas have their local guidance, thus in policy, different sets of policies or alternatives can be used. This option can be required under divergent degree, from simply meeting the standard to achieving to reach a high level. The scope of the requirement can be diverse: limited to a specific kind of building type, such as a shopping mall or office; limited to a certain scale; limited to certain agencies, such as all the public sections.

Encouraging Achievement of Certain Green Building Standards: Unlike the previous mandatory approach, this action officially encourages agencies to voluntarily make green building a priority.

Create a group or assign an agency to invent or develop standards or plans: Government agencies would like to develop local standards and provide guidance for green building according to the local context and climate. If there is no ready standard they can use, a working group can be established to fill this gap. This movement provides a clear leadership to support green building and creates "a fair and open process" (A. R. Pearce, et al., 2007).

Programs

Programs provide inspiration and guidance for green building practice. Various programs have been implemented, from formal policies to an open basis. The success of programs is determined by the source of funding to support, promote and continue these programs.

Incentives: Rather than require agencies to meet certain green building standards, this approach offers a reward to encourage agencies to pursuing green practices. It is a motivation and a showcase leading other agencies to follow. Government offers of incentives can be varied: some provide direct monetary subsidies; some provide tax exemptions; some reward with additional GFA or a reduction in the lending rate.

Training: Training provides professionals with general sustainability and green building principles. A regular training program updates professionals with new concepts and innovative technologies. Professional training programs, such as seminars, can be an opportunity to share and communicate, where people learn innovative practices from each other. Some agencies require these training hours as a condition to acquiring professional certification on an annual basis.

Implementation

Implementation is a step when agencies need to find out what program they are going to meet, which level they are about to get and how to achieve their goal. Those agencies always need assistant from green building experts in implementing a green building certification system, including technical support, guidance documents, etc. Other successful projects would be a showcase and guidance.

Technical support: Technical support is an efficient approach to promote green building. Experts in various fields of green building provide clients with their knowledge of sustainable design. It is direct and useful in supporting project certification, and avoiding ignorance of new and innovative techniques.

Guidance Documents: Many agencies develop guidance documents to explain green building requirements in a more concise format and specific relevant content. They can serve as guidebooks with selected checklists or strategies that were successfully used in previous projects (USGBC, 2002). Some documents highlight more detailed information about achieving those items.

Model Projects: Agencies will be largely inspired by their counterparts. Successful projects can be a model to encourage others to follow. Innovative technologies and new ideas tested in those models would provide compelling persuasion, indicating maturity and localized benefits of the technologies.

Evaluation

Evaluations highlight individual building's effectiveness and compliance to green building standards (A. R. Pearce, et al., 2007). In most cases, government officials explicitly demonstrate how green building should be measured and reported according to the regulations. It is a process to check if the building's expected performance will meet the standards in the design phase and the operation phase.

Certification: Currently, there is a wide range of certification systems for green building. Different countries have developed their own green building rating systems. Projects certified by these systems are generally a straightforward evaluation. These certifications are usually conducted by a non-profit organization or an alliance organization. However, some agencies have complained that the money spent on third party certification should be put directly into the building itself.

Regular Reporting: Many countries set a regular reporting system to measure the building's actual performance after design phase certification. The data collected in various projects are grouped into a database under diverse types of buildings, which can track the efficiency of different facilities and form updated standards for future programs.

Performance Monitoring: It is necessary to monitor a building's actual performance. It ensures that those reported energy-saving facilities are in use and checks the whole building's performance in practice. If any problem is found, further action will be proposed to handle the problems and ensure a real "green" building.

Post-occupancy evaluation: A green building may not guarantee a comfortable interior environment. Further, intention of green design may not result in it in practice. After buildings have been built and stably operated, a post-occupancy evaluation is useful to collect feedback from the building's occupants and ensure that the building meets green building requirements. It involves a systematic evaluation of opinions about the building in use and is supplemented by environmental monitoring to identify ways to improve building design, performance and fitness.

COMPARISON BETWEEN HONG KONG AND SINGAPORE

As leaders of Asian economic development, both Hong Kong and Singapore have a prosperous construction industry with a free market and well-educated professionals. They share comparable legal systems as former British colonies, dominated by Chinese Culture. The similar climate background in both cities guarantees a comparable lush green environment. The tropical climate in Singapore and sub-tropical condition in Hong Kong provide sufficient rain and sunshine. In terms of green building design, these two cities share plenty of common strategies, such as energy-efficient air-conditioning systems, building plans for natural ventilation, sun-shading devices and low-E glass.

However, in green building promotion, these two cities have adopted distinct policies. Singapore utilizes a government led model. It developed its own green building assessment scheme – Green Mark (BCA, 2005), with a clear roadmap. Hong Kong depends on non-government, voluntary scheme with a free market. Several agencies in Hong Kong promote green building: China Green Building (Hong Kong) Council promotes green building according to a national Green Building Labeling System; BEAM Society, which is based on BREE-AM (UK), developed a local green building assessment tool and training for professionals. After years of no significant progress in green building

revolution, the Hong Kong government has started to offer incentives to drive green and sustainable development in building.

Hong Kong

Hong Kong has launched a green building certification system in an early time. However, the fact that only a few buildings have received certification shows that the voluntary program in Hong Kong may not be effective.

In 1998, the Electrical & Mechanical Service Department (EMSD) started a series of Building Energy Codes (BECs) on a voluntary base. The Hong Kong Energy Efficiency Registration Scheme for Buildings is one of them. It was launched to help save energy in lighting, air conditioning, electrical, elevator and escalator installations (Lau & Greenpeace, 2011). It was prepared for a wide range of applications, from private residential building to commercial, office and other public ones. However, statistics show that private sector developers seldom joined this scheme. A survey conducted in 2005 indicated that less than 2% of the buildings have applied for this certification over five years, even though 67% of stakeholders in related sectors were aware of the scheme.

Certification

Initiated in 1996, Building Environmental Assessment Method (BEAM) is the first green building certification system in Asia. It is a voluntary scheme tailored for high density urban development in Hong Kong (Ng, 2013). The rating system assesses building's environmental performance issues, focusing on site, material, energy, water, indoor air quality and innovative design. BEAM was enhanced in 2010 to meet higher expectations in sustainability and encourage passive design.

BEAM experienced a slow movement (Fig 2). Within 14 years, from its first launched time until 2010, only 210 projects were certified[1] . This is in comparison to Green Mark in Singapore, which from 2005 to 2010 had more than 500 projects[2] participate in the program. A dramatic change happened in 2011, when the Building Department in Hong Kong promulgated that BEAM Plus would be a prerequisite for the granting of GFA concessions. To date, more than 300 projects have been registered or certified for BEAM Certification[3] . Even then, green buildings in Hong Kong are far from sufficient. The voluntary-based scheme measurement is not persuasive enough, and legislation is needed.

Green Building Promotion from the Government

Clearly, the trend in embodiment of these codes gradually changes from voluntary to mandatory, which indicated that Hong Kong government commenced involving in green building (Table 1). However, in contrast with the standards of developed countries, the standards of Hong Kong are set at a low level for building energy saving (Lau & Greenpeace, 2011).

The Hong Kong government has announced a series of measures to advance building design into a high quality and sustainable way[4] . Sustainable building design guideline proposed several approaches to realize green; granting of GFA concessions tries to stimulate developers' interest; and more requirements are added to buildings' energy efficiency.

In addition, government projects play an exemplary role in leading the green market. One of the public housing projects, Upper Ngau Tau Kok Estate, Phase 2 & 3 was the first Three-Star[5] Project in the Green Building Labeling System in Hong Kong. Instead of applying expensive mechanical facilities, it successfully adopted applicable technologies and passive design to realize a low-cost, high-quality model. Studies have revealed that projects from the government, public institutions and local communities usually have better performance in sustainability (Ng, 2013), demonstrating that the public sector is enthusiastically pursuing green building.

Green Building Promotion from Non-Government Organizations

Hong Kong has embraced several non-government and non-profit organizations to promote green building, such as the Business Environment Council, Construction Industry Council, BEAM Society, Professional Green Building Council, Hong Kong Green Building Council and China Green Building (Hong Kong) Council (CGBHKC). These agencies, involving professionals from building related fields bridge government and corporations with environmental responsibility.

Hong Kong, in many aspects, has an open and free market. Naturally, the green building certification system is driven by the market. BEAM, LEED and GBL occupy their own market share. Their impact in Hong Kong is far beyond building itself. These certification systems inspire professionals locally. Hong Kong has more than 400 LEED AP, 500 BEAM Pro (BEAM Professionals) until 2011 and 100 GBL Managers, which largely enhance professionals' quality. These trained employees, in return, push forward the certification market. Take LEED Projects in Hong Kong as an example. Between 2009 and 2010, more than 300 LEED AP were certified, which resulted in three times more LEED projects registration one year

[1] http://www.beamsociety.org.hk/

[2] http://www.eco-business.com/features/singapore-growing-asias-green-building-centre/

[3] http://www.hkgbc.org.hk/eng/BeamPlusDirectory.aspx

[4] http://www.info.gov.hk/gia/general/201101/31/P201101310250.htm

[5] Three-Star is the highest level in China Green Building Label (GBL) system, which is launched by China Green Building (Hong Kong) Council, as a green building evaluation system.

later, compared with the total number of LEED projects before 2009.

The two local certification systems, BEAM and GBL, provide localized guidance according to Hong Kong's context. BEAM updated annually. BEAM Pros are required to advice on plan, design, construction and renewal process of green building based on the newest standards and codes in Hong Kong. CGBHKC launched continuous trainings for professionals. Every year, all the GBL managers have to renew their designation by taking extra classes, seminars or earning green building related publications, which tries to guarantee professionals' enhancement. Exhibitions on demonstrated projects, organized by CGBHKC, were held in popular malls to propagate green buildings to public.

The promotion of green building is planted in architects training within university education. In the University of Hong Kong, a course about green design strategies based on LEED, BEAM and GBL standards was introduced and developed to be a compulsory course for master architecture students. Studios and workshops were launched to involve students to green building projects visit and sharing meetings with experienced architects.

Singapore

Singapore leads sustainable environmental performance in the whole world. Interestingly, when compared with other developed countries, Singapore started green at a relatively late time. Only until 2005, the Building and Construction Authority launched its local green building certification system- Green Mark (Fig 3). However, its speed of development was surprisingly fast. Five years after the system was introduced, in 2010, the number of certified buildings reached more than 500[6], doubling the number of green projects in Hong Kong in less than a decade time. The success of promoting green building in Singapore was due to government efforts.

A Clear Roadmap with governmental leadership

Vision and commitment are crucial drivers for green building sectors. Planning ahead is absolutely necessary for a revolution. The success of Singapore follows its Green Building Master Plan (GBMP). Singapore released its first GBMP in 2006, which set $20 million as direct monetary incentive to spur the private sector and established a research fund to encourage advanced technologies and solutions for cost-effective green building. This plan definitely expressed governmental leadership in green building. The second GBMP (2009) has planned 20 years ahead with the ambitious but clear goal of having at least 80% of buildings achieve the Green Mark certification rating by 2030[7]. All of the existing buildings owned by government sectors need to meet the Green Mark Gold Plus standard by 2020, while new, larger air-conditioned public sector buildings have to qualify on an even higher standard. The rigid demands on government buildings demonstrate the government's determination in playing an exemplary role.

Mandates

When analyzing the trend of the number of Green Mark buildings, it becomes apparent that there has been a dramatic jump in Green mark buildings. From the years 2005 to 2008, only 239 projects received certification. However, between 2008 and 2012, the total project number has leaped to 1,247 and continues to grow. Apparently, the huge wave of green building was inspired by mandatory requirements, such as laws stating that all new large and major retrofitting public sector buildings have to meet Green Mark standards. In key growth areas, higher green building requirements are related to land sale conditions. Thus, urban development and green building are tightly integrated as a single process.

Incentives

The Singapore government offers attractive incentives for the private sector to spur implementation. Monetary rewards and GFA concessions are the two major ways. Incentives that are given out follow an easy-to-hard sequence. At the very beginning, monetary incentives start on new buildings, which is easier to realize compared with retrofitting existing buildings. After the first phase, direct monetary incentives for private new buildings are stopped and GFA incentives commence with much higher requirements on green building performance. At the same time, the government starts to inspire existing building renovations. A bounty is provided to the public on a first come first served basis, which encourages market competition and a quicker response in the building and construction industry.

Reporting

A green building design cannot promise a green building performance. Singapore requires all certified buildings to undertake reviews every three years during their operational phase, in order to measure the buildings' compliance.

Training

Professional training is necessary to raise the overall professional level. Singapore provides several training courses on green building knowledge for professional designers, engineers, and educational courses for undergraduate and master students. Many consulting firms were launched by these graduates to provide technical support for green building. With knowledge and resources in sustainability, their branches have

[6] http://www.eco-business.com/features/singapore-growing-asias-green-building-centre/

[7] http://www.bca.gov.sg/greenMark/others/gbmp2.pdf

expanded internationally and experts are exported to support other countries' green practices.

Research

Leading the group requires solid technical support. The Singapore government has never hesitated to fund research institutions to conduct advanced studies. Research is a significant part of the Green Building Master Plan. The government is expecting pilot projects to save 20% more energy, compared with current platinum requirements and tests furthering technologies for a Zero Energy Building Project. Experts and practitioners all aim to fulfill the government's ambitious goals.

CONCLUSION

This paper captures key programs and various approaches taken by governments to pursue green building. The comparison between Hong Kong and Singapore's green building promotion programs indicate that a voluntary scheme may not be sufficient. A government should lead green building movement with clear goals and make active efforts to motivate the industry. In moving towards green, appropriate incentives can be an effective stimulus and a carrot and stick system is also necessary. This paper also advocates a further approach to evaluate programs' efforts and their impacts on a wide range of project practices. Further research is required in order to discover a better understanding of how the context affects the impact of the programs. Based on the findings of this paper, future studies should expand to other agencies, such as private design corporations, developers, governmental sections as well as institutions, and identify their responses to these police programs.

ACKNOWLEDGMENT

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Table 1Policies related to green building in Hong Kong

Implementation Date	Policies		Embodiment
1995	Building (Energy Efficiency) Regulation		Mandatory
1998	Voluntary Implement ation of the Building Energy Code	Lighting Installations	Voluntary, become mandatory since 2005
1998		Air Conditioning Installations	
1998		Electrical Installations	
2000		Lift & Escalator Installations	
2003		Performance-based Building Energy Code	
2008	Guidelines To Account For And Report On Greenhouse Gas Emissions And Removals For Buildings In Hong Kong		Voluntary
2009	The Energy Efficiency (Labeling of Products) Ordinance		Mandatory
2012	Mandatory Implementation of the Building Energy Code		Mandatory

Figure 2 Number of BEAM Projects in Hong Kong

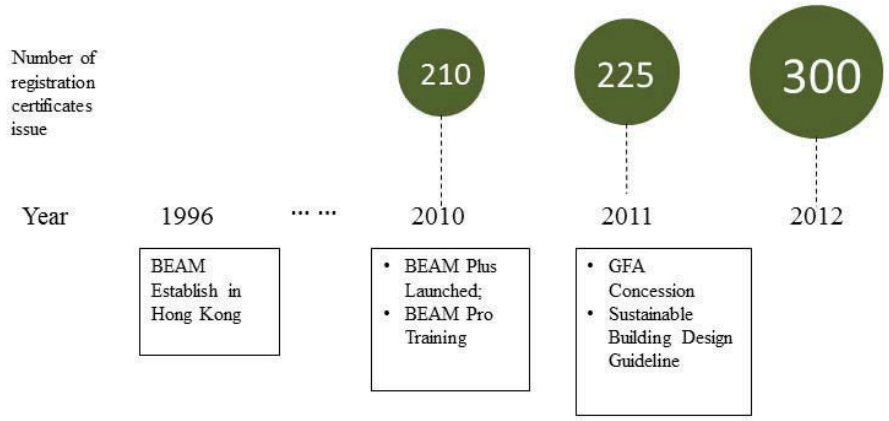
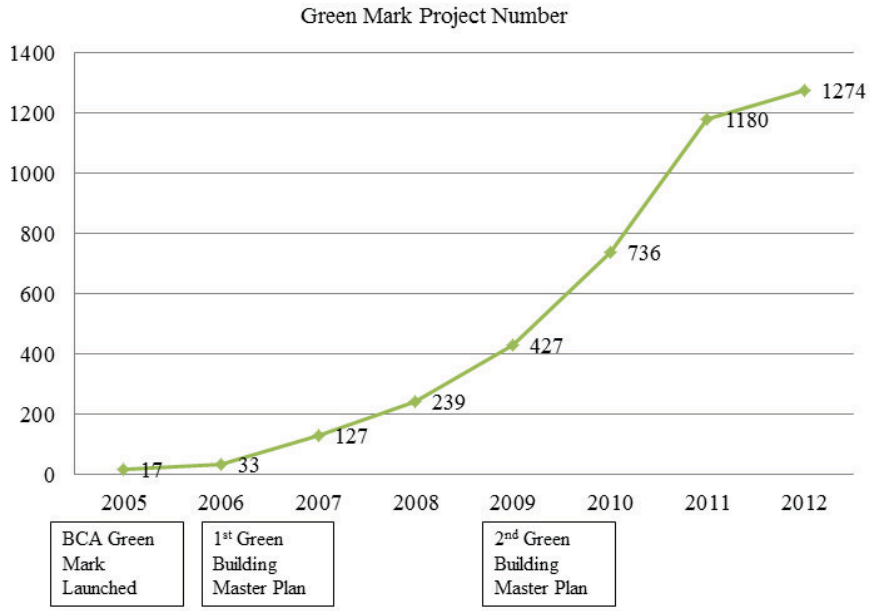


Figure 3 Number of Green Mark Projects in Singapore



CONTEMPORARY SPACES OF ISLAM, BUILT ENVIRONMENT AND THE REPLACEMENT OF CONVENTIONAL FORMS: AN ASSESSMENT

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ABSTRACT
In Abu Dhabi the emergence of new mosque forms comprise a complex strategy that attempts to sustain cultural identity, sustainability and architectural form. The contemporary mosque of Fatima bint Mubarak in Abu Dhabi represents a new design approach that challenges traditional forms in an attempt to advocate architecture that builds on sustainable designs. This study assesses the contemporary form of the mosque and the absorption of heat gain and loss levels in accordance with the required cooling loads, and thermal comfort levels. The aim is to integrate environmental and sustainable concepts in contemporary designs, therefore, two scenarios were tested; the first as existing with its glass curtain walls with a projecting upper floor to provide shade on three of its facades, and a second scenario was based on thick stone walls with small windows. The second scenario was inspired by contemporary mosques that hinge on local/traditional adobe mosques in the United Arab Emirates.

Keywords: *Abu Dhabi, Sustainable design, Contemporary mosques*

INTRODUCTION

The Fatima bint Mubarak mosque currently emerging in Abu Dhabi represents a new approach to the design of religious space, which may be considered ahistorical when compared with traditional mosques such as the iconic Sheikh Zayed Grand mosque which referenced its domes, minarets and decorative scheme to well known historic monuments. Mosques in the Muslim world have always played an important role as iconic structures that shape the identity of the city, in addition to a congregational role that disseminates to the community socio-cultural and religious messages. Today newly emerging mosques such as Fatima Bint Mubarak (Figure 1) manifests through its features the possibility of integrating sustainable design in public buildings with specific forms and functions, this is further accentuated through its form and spatial arrangement. The main feature of the interior form is a twisted pyramidal roof with a large glass triangulated section that lights the black marble *qibla* wall (facing Mecca), both pyramidal roof and black *qibla* wall represent an attempt at creating an ahistorical abstract space that links earth and sky. The mosque was designed by CAP-Concept Architecture and Planners in completed in 2013 its extensive use of glass facades is unique to the United Arab Emirates which has a long history of constructing adobe mosques with thick walls and small windows due to its hot humid Gulf climate. Contemporary mosques create new paradigms of architectural education, through the study of how sustainable design can be applied to an Arab/Islamic religious space. They represent spatial connections between the modern Muslim world and expatriate communities living in Abu Dhabi. (Abdel-Hadi, 2012) The Fatima bint Mubarak mosque has an approximate area of 2800 square meters, planned for 5000 worshipers. This paper explores from an architectural design and environmental perspective different aspects of this contemporary mosque such as its thermal comfort levels, and heat emissions.



Figure 1. Fatima bint Mubarak mosque

There are other examples of contemporary mosques such as the Sheikha Salama mosque (2010) which also reinterpreted local tradition, but opted for thick walls clad with stone, wooden pergolas covering its courtyard and GRC grills shading its windows, this mosque inspired the creation of an alternative design with solid walls. Two models were created in Ecotect one to test the mosque as built and the other replaced the glazed surfaces with thick solid walls with small windows. The juxtaposition of these scenarios using a simple software aimed to test the possibilities of integrating environmental studies in design studios using an existing case study known and physically accessible to student architects. The attempt to integrated to disciplines aims to encourage

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future architects to analyze their conceptual designs possibly change building skins, proportions of solid and voids, as part of the design development process. The creation of models/scenarios and studying the shadow range simulations (Figure 2) proved that it is possible to develop designs beyond the current trends dominated by architecture of the spectacle that has become popular with students because of the availability of digital software. In Abu Dhabi there is a plan to promote an image of a modern city that sustainable development of its community, and not only to mass tourism. This image is different from neighboring Gulf state cities such as Doha, Dubai and Manama where the urban image is dominated by high-rise glass tower that brand each city with an image of wealth to attract investors. Nonetheless, applications of sustainable design in public buildings is challenging and requires an understanding that sustainability so as not to produce monolithic concepts similar to the 'International Style' of architecture developed in the mid 20th century, in contrast the idea is to produce a network of ideas that are to become part of a design culture. (Gurel, 2010) Most of the challenge emerges from the influence of air-conditioning systems on architecture in oil rich states, as manifested by extensive use of glass on the facades of the twisted and morphed towers of Dubai were designers and clients have become more concerned to create an architecture of the spectacle and less concerned about how their buildings relate to factors such as the movement of the sun, direction of the wind and changes in outside temperatures. (El Demery, 2010)

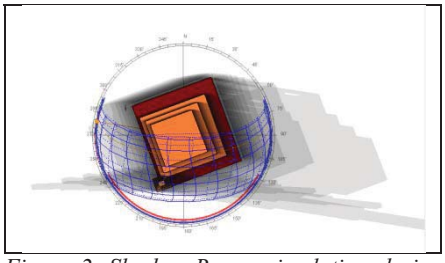


Figure 2. Shadow Range simulation during the month of August

The design of contemporary mosques is at its early stages in the UAE, but has become part of a process of urban transformation and gentrification of some sections of the city. In the city of Muhammad bin Zayed on the boarders of the industrial neighborhood of Mussafah in Abu Dhabi the mosque of Fatima bint Mubarak represents a significant departure from the usual precast concrete mosque architecture and through the development of its surrounding landscape a new gentrified quarter is being created. A paradigm shift is occurring to create new buildings that are acceptable to the community and also sustainable, a shift from precast concrete generic structures that created a melancholic image of the city in the 1980's. This new generation of mosques departs from both previously mentioned prototypes to create new forms of religious spaces that reject elements that have traditionally been associated with mosques. Contemporary mosques emerging in the UAE create a synthesis of old and new, their rectilinear forms cubical forms devoid of excessive ornament manifest a mixture of individual Islamic elements that are supported by a long tradition in the Gulf of mosques with interiors that were devoid of elaborate decorative themes. (Jahic, 2008) The structure of these mosques departs from the traditional mosque design; an example that is widely published is the Grand National Assembly Mosque in Ankara designed by architects Behruz and Can Cinici in the 1990's. The architects replaced the conventional dome with a pyramidal one to depart from tradition and enunciate the concept of the modern Turkish Republic as an era that is distinct from its Ottoman past. Re-interpreting tradition is manifested in the mosque's discrete decorative them, materials and the creation of a glass *mihrab*-prayer niche in the *qibla* wall (direction to Mecca) to integrate the interior of the mosque with its surrounding environment. (Al-Asad, 1999) As Salma Damluji outlines successful practice in constructing such an urban image in the Gulf needs create forms that are sustainable and based on successful references of contemporary architecture developed in a sophisticated vocabulary. As outlined by Hasan Uddin Khan the mosque of the National headquarters of the Islamic Society of North America (1981), The Taric Islamic Center in Toronto (1991) and the Sherefuddin Mosque in Bosina (1980) are all examples of contemporary mosques that were based on geometry and the resulting proportion and that indicate an awareness to develop mosque form as part of the communal interest in sustainable development, entrenched in Muslim doctrines. (Khan, 1994) The Fatima bint Mubarak mosque not only acts as a new formulation of religious space through its use of a twisted conical roof but also respects the surrounding environment. Subtle shapes and simple forms characterize all the elements of the mosque whereas the desert sand color gives the façades a distinctive quality. Although interpreted in a contemporary manner the square minaret with a step-like ending contribute to the revival of the regional tradition. Its adoption of a twisted minaret is a contemporary translation of the *malwiya* minaret of the Great Mosque of Samarra (848). In the process of constructing a contemporary mosque that has

historical linkages the designer did not create a facsimile of the Great Mosque of Samarra in contrast a process of inclusion and exclusion of traditional forms represents a bold departure from the constraints of past, and opens up new avenues in the debate about style and built environment in emerging Gulf cities. Thereby, these manifestations of religious space, offer new socio-cultural contexts, and warrant a study to assess their design sustainability, to assess the application of ecological design principles that aimed to reduce cooling consumption loads.



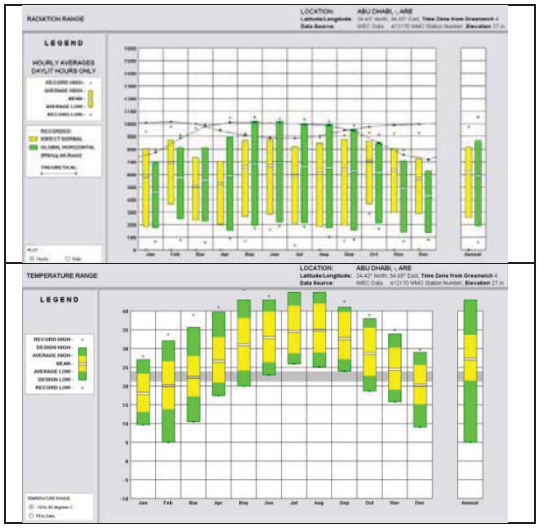
Figure 3. Shaded glass surfaces and colonnaded corridors to access to the prayer hall

Contemporary mosques emerging in Abu Dhabi begin to partake a larger role to support sustainable policies following the guiding principles of Estidama and the Abu Dhabi 2030 plan, they build on a form of authenticity that replaces conventional regional styles, yet uses selected forms such as minarets, pyramidal domes, glazed surfaces from a broader spectrum of contemporary mosques in the Muslim world and beyond. The overhanging eves and brackets decorating the portico create an intermediate space that introduces the user to the sanctified space. (Figure 3) The design enables a gradual transition from public to semi-public and finally to private space for prayer. Linkages can be made to the Great mosque of Xian (1398-1413) in China and Masjid Agung in Demak (1474) central Java Indonesia represent examples were mosques reacted to the environment by applying projecting porticos supported by wooden columns to shade the walls of the mosque and thereby create a passive cooling system within the context of cultural traditions. The prayer hall itself has multiple large openings that allow easy exit and ventilation of the enclosure. The pyramidal roofs of Asia mosques had a positive effect on cooling the interior of prayer halls before the advent on air conditioning. (O'Neill, 1994) The use of brickwork, and terracotta tiles on the facades of contemporary buildings to reflect on cultural and sustainable design have been subject to experimentation by architects such as Rasem Badran and Rifat Chadirji and Hassan Fathy who developed the foundations for a culturally rich architectural idiom that would bring tradition and modernity into contact. Their approach was to focus attention on a building facade that could carry explicit and wide-ranging references to the architectural heritage of the Arab region, and beyond. As Khan highlights that in this century, the issue of sustainability has become the forefront in urban development especially for emerging communities in the Gulf. In Abu Dhabi sustainability has become a major part of the design configuration of the architecture of Muslim communities. The historic quarter of Al-Bastakia in Dubai with its wind catchers *barjeel,* adobe architecture and shading devices developed overtime to become part of the UAE's national heritage, in spite of their importation from neighboring countries with migrant mercantile communities. Courtyards, colonnaded porticos locally known as *liwans* were used as male meeting spaces, and gypsum window grills have been used to control the entry of the sun and have developed overtime as part of building traditions in the Muslim World. (Khan, 1994) In the Fatima bint Mubarak mosque air-conditioning cannot be avoided in the hot summer months because sandstorms and dust represent another dimension that is associated with Gulf climate. However, the aim of new designs in Abu Dhabi is to reduce air-condition usage by incorporating sustainable design criteria such as minimizing or eliminating West-facing glazing to reduce summer and fall afternoon heat gain. Good natural ventilation can reduce conditioning during the moderate months if windows are well shade and oriented to prevailing wind breezes, especially if most of the glazing of the facades is oriented to the North. The new design guidelines in Abu Dhabi 2030 plan are the baseline of the climatic analysis that is to be demonstrated in the analysis section.

MOSQUE ANALYSIS

The UAE has a hot climate with humidity prevalent on the coastal regions while being very dry inland, especially during summer months. On the coast, humidity can be in excess of 90% in the summer. (Source: National Center of Meteorology & Seismology (NCMS) June 2013, http://weather.adac.ae). The intensity of the solar radiation depends on altitude of the sun and the quantity of particles in the atmosphere. Direct, diffuse and reflected solar radiation are types of solar radiation that will affect the building and the amount of heat transferred into it. In Abu Dhabi the high humidity and cloud cover reduce direct solar radiation and the reflected radiation from the ground

is low. The climate can be categorized into hot summer months from May to September with excessively high temperature and humidity values and warmer months between Octobers to April with relatively higher comfort levels as shown in (Figure 4). In Abu Dhabi humidity is high throughout the year, with average relative humidity above 60% and commonly around 100%. It's considered to be the major problem regarding the weather in Abu Dhabi. Due to the hot humid weather of Abu Dhabi during summer there is a need for good ventilation at mosques; however, natural ventilation is not desirable in many buildings over the UAE as it reduces the indoor air quality due to the presence of dust and thus the dependence on mechanical cooling systems increases. The mechanical cooling consumption in public buildings is extremely large due to the great difference between the indoor ambient temperature levels and the thermal comfort zone. Bridging the gap between the two temperatures would contribute to lower artificial cooling loads that certainly lead to energy savings. Generally, passive design is to extract the maximum benefits of the natural surrounding environment to be used in a design that reduces the heat gains and enhances the heat loss during summer. Traditional design of the Islamic world, which extends over a wide geographical area with various climatic conditions, such as the moderate, hot and humid, the moderate tropical, and the predominant hot dry climates, has always been able to effectively respond to its natural environment. The comfort zone has been the subject to many studies.



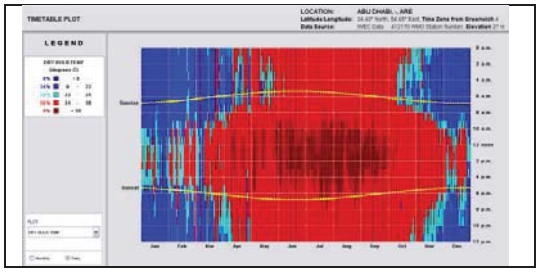


Figure 4. Abu Dhabi climate charts

The diagram shows that in Abu Dhabi with a relative humidity of around 70% and temperature above 30 degrees Celsius in June the internal thermal comfort is never achieved without applying passive or active cooling techniques such as sun shading, natural ventilation, direct evaporative cooling, fan forced ventilation cooling, and most of all conventional air conditioning is provided, each is shown with a percentage according to the need. While in December 12.6% of the time the internal comfort levels are achieved naturally. But yet sun shading, high thermal mass etc. and other factors are needed to maintain the thermal comfort. Through the use of the 'climate consultant' software building design guidelines are involved to listen to nature in providing a comfortable and healthy varying indoor climate in an environmentally sustainable way. The objective is to specify the aspects (temperature range, wind speed, illumination etc.) needed to reach the comfort zone that is also specified by this software in a certain stage. The design guidelines provided by the software has been used as the reference for the analysis done to Fatima bint Mubarak mosque. The orientation of the mosque is slightly tilted towards the North West with a solid stepped minaret located on the south west angle of the prayer hall. The minaret location and design provides shading on the west façade during the peak thermal stress period of the day, which reduces the amount of heat gain. Central to its design is the spiral conical roofing structure with a large triangulated glazed section on the East. Domes are considered good climatic features of a building in hot climates as it promotes the 'stack effect' (hot air circulates upwards while colder air goes to the bottom of the space) ongoing within any space. If an opening on the top part of the dome is provided it would actually accelerate the stack effect and release the amount of heat accumulated within. The solar gain is maximized on horizontal planes –such as roofs- in hot climates. Due to the presence of the huge glass dome centralized on the rooftop the amount of solar heat gain is reduced due to the angle of incidence between the sunrays and the plane of incidence. The dome has an opaque cladding and

openings that promote indirect sun light. The spiral dome has a large glazing on the east direction that allows a large amount of sunlight and to enter to the space during early mornings, which is considered of low thermal gains. The lower part of the north, east and south facades is recessed with concrete columns forming a shaded passage shading the glazed parts. The three glazed facades have shaded recessed windows with louvers, the solid parts of the mosque as a whole covered with horizontally ribbed tiles to provide shade. The north and south facades accommodate male and female entrances with shaded corridors. The West façade (*qibla* wall facing Mecca) is completely solid which reduces the heat gain during the peak thermal stress period of the day during the afternoons in summer months. The material used for the building external skin 'clay brick cladding fixed on brick walls' acts as a high thermal mass for the building. High thermal mass actually is recommended for hot arid climates that reduce the amount of solar gain during the day. The surrounding structures, vegetation and material affect the buildings thermal transfer process throughout. The location of the mosque in Mohammad Bin Zayed city which is a low rise residential district with relatively wide paved asphalt streets that increase the solar gain levels during the day and increase the radiations during the afternoons and evenings constituted a challenge that was met by many of the environmental design applications. Generally the building overall design is considered as one that has passive design aspects that minimize the heat gains during summer, which is our main concern in the Gulf climate, thereby heat gain is minimized the need for artificial cooling is reduced accordingly.

SIMULATION

Ecotect has been used to analyze the existing building scenario in comparison to a second scenario created with different principals. The simulation has been conducted during the hottest six months of the year, which is between April and September. (Figure 5) Several factors where monitored but most importantly the cooling loads, which indicated the amount of heat losses and gains affecting the building. Image below represents the shading analysis of the scenario 1 representing the existing mosque Fatima bint Mubarak mosque during the hottest six months of the year between 8:00 and 16:00. Due to the position of the sun the west and north facades are mostly shaded between 8:00 to 10:00 and by noontime all facades except the north facade are exposed to the solar gain. During afternoon which is responsible for the hottest thermal sensation of the day due to excess heat radiations and emissions, the south and west facades are being mostly exposed to the sun leaving the east and north facades shaded. The shade length is minimal in June and July due to the solar angle, which increases the outdoor air temperature accordingly. Openings on the south façade should have been minimized especially glazing at the lower part of the building that adds a large amount of heat load into the space. The west façade was well designed as the openings were completely avoided in there.

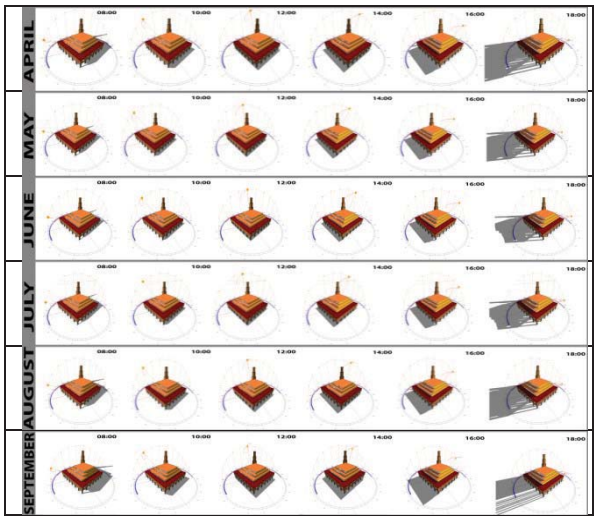
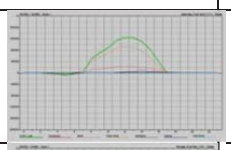
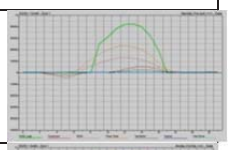
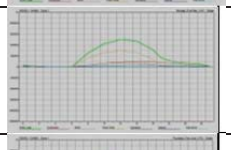
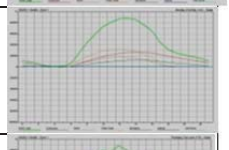
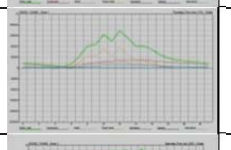
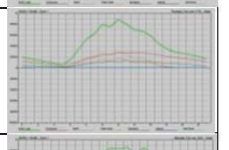
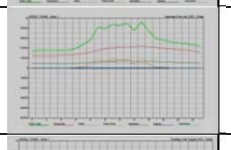
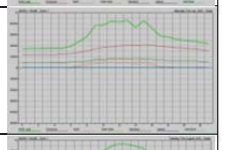
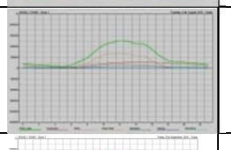
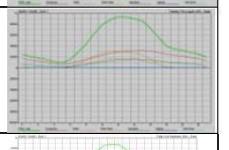
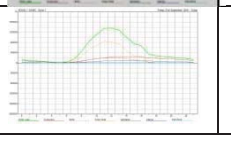
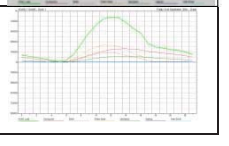


Figure 5. Hourly shading of Fatima Bint Mubarak mosque Scenario 1

The graphs below revealed quite an interesting behavior of the two comparative scenarios. Initially we expected scenario 1, which is an analysis of the mosque as built, with its recessed base surrounded by a row of modular column that provides more shade, to demonstrate a lower cooling load the second scenario having the solid walls with no shading feature. Yet the simulations done by Ecotect revealed that the second scenario requires a lower cooling consumption than the first scenario as shown in Table 1. The analysis of the hourly heat gains and losses shown in Figure 6 & Table 1 indicates that scenario 2, where the glass facades of the mosque were replaced with an extension of the solid walls of the mosque recorded higher values in other aspects as well such as direct solar radiation and conduction. The values recorded by both scenarios shows that the highest HVAC loads are required during midday at 13:00 o'clock where the direct solar gain is at its peak. The large amount of glazing included in the lower part of scenario 1 added a large amount of heat gain into the internal space. The heat absorption of the passage components surrounding the mentioned glazing such as columns and the flooring also amassed more heat around the glazing that proved to

slow the nocturnal heat losses, which was tested through another scenario that excluded these columns.

Table 1.
Graphs indicating the behavior of the two comparative scenarios

	Scenario 1	Scenario 2
April		
May		
June		
July		
August		
September		

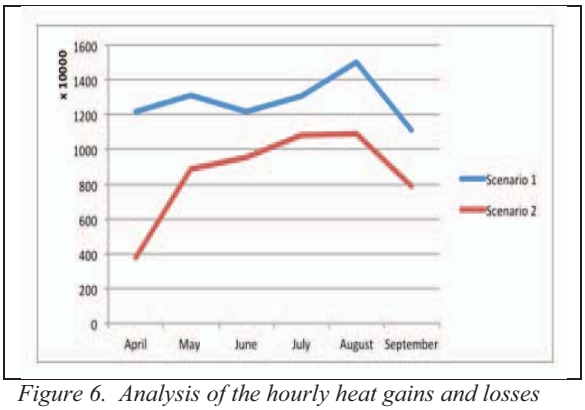


Figure 6. Analysis of the hourly heat gains and losses

CONCLUSION

To conclude, our preliminary study indicates that the mosque respects the local values, climate and environment and gave the design the sense of the sought continuity. The Fatima bint Mubarak mosque interrogates regional building traditions by creating a textured assemblage of abstract vernacular forms indicating that past, and present, can and should be brought together under the penumbra of sustainable design. The mosque employs an array of screens integrated within passive solar control attempts through clay tiles, corbels and tent like shading devices currently being added in the space in front of the mosques entrance to create an extension for prayer spaces and to regulate both thermal radiation and daylight from the tiled flooring. Ecotect was used to create two scenarios for the mosque. The aim of the two scenarios is to examine the two methodologies of mosque construction in a hot humid climate, the traditional line of thought that supports thick walls, carved window screens and wooden shading devices over the courtyard, and the modern theory that supports thin partitions/shaded glazed surfaces as a building skin. The local climate is considered quite challenging to apply an ecological building that responds to nature. The reason for that is not only the dependence of such structure on artificial cooling due to extreme summer conditions, but also due to the complexity of the behavior of the outdoor parameters such as temperature, humidity and wind. The average of the daily thermal comfort levels studied in a certain month is an outcome of hourly-measured values throughout each day on a daily basis. Therefore a critical balance required to be achieved between the diurnal heat gain and the nocturnal heat loss cycles, which the outcome of the current investigation accentuates upon. In the two case studies addressed in the current investigation the mosque of Fatima bint Mubarak express a different approach where application of theoretical studies produced mosque architecture that utilizes shade as a heat avoidance cooling technique. In many ways these contemporary mosques managed to successfully combine the indigenous shapes and materials such as a framing the walls with ribbed clay tiles and curtain walls shaded by projecting cantilevers and colonnaded arcades but more important this study indicated with it is possible to integrate environmental studies in the design studio without sacrificing the final product.

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SMART ENERGY MANAGEMENT SYSTEM FOR ZERO ENERGY BUILDINGS

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ABSTRACT

The paper presents the concept and the outline of the smart energy management system developed by the authors. Initially, the system had started as a sort of Energy Information System (EIS) just for real-time monitoring of operational energy use of building. Through the application to varieties of buildings for previous decades, the system has included analytic function to identify sources of waste and inefficiencies in operation of buildings. Then, it has innovated to be the system that enables proactive control of operational energy use in buildings by introducing the heuristically upgradable prediction of energy demand of buildings. The authors installed the system to experimental zero energy building constructed in the Komaba campus of the University of Tokyo. The smart energy management system has enabled integrated proactive control of operational energy use of the building. The annual operational energy use of the building between 2011 and 2012 is lower than the target performance defined in the initial reduction scenario.

INTRODUCTION

Operational energy use of a building is the largest component of life-cycle energy use and occupies around 80% of the total life-cycle energy use (Cole et.al. 1996). However, the actual operational energy use of a building has a significant difference with simulated energy use of the building at the design stage. It seems to be due to;

- restricted information and knowledge transfer from supply-end agents to user-end agents
- difference of assumed conditions and actual conditions in operations of building
- unpredictability of occupants' or residents' behaviour and preference
- insufficient commissioning

Therefore, operation management of buildings need to be adaptable to unforeseen and ever-changing modes of operations. The needs require the development of innovative method that enables proactive control of operational energy use in buildings. If such method could be usable, the method could be an effective tool to zero energy buildings by monitoring and mitigating the difference between the actual performance and the targeted performance at the design stage.

This paper aims to illustrate the concept and the outline of smart energy management system for operation of buildings developed by the author. Then it also aims to discuss on the effectiveness of the system for operation of zero energy-oriented buildings.

SMART ENERGY MANAGEMENT SYSTEM FOR PROACTIVE CONROL OF OERATION

Respecting on the significant gaps between the actual performance and the targeted energy performance at the design stage, the authors had developed the smart energy management system. Initially the system only involved the functions of;

- the measurement of operational energy use and related environmental conditions
- the aggregation and benchmarking of collected data from digital sensors

Through the application, it has included the function of;

- the analysis to identify waste and inefficiency in operational energy use of buildings,

Further, the system has been innovated by the introduction of ;

- the method of parametric explanation of operational energy use of buildings.
- the method of heuristically upgradable prediction of energy demand of buildings
- the method of feed forward operation control of building services and equipment based on energy demand prediction

The following is outline illustration of the above functions and methods.

Initial functions: Real time energy use monitoring

Figure 1 gives the outline of the ICT based method of measuring of operational energy use of buildings and related environmental conditions. Digital sensors installed in the buildings measure energy use and related environmental/operational conditions. They send the measured data to off-site servers through control unit in the buildings. Compared with generic Energy Information Systems (EIS), the developed system includes more holistic set of sensors to measure state of art of environmental conditions because the method aims to assure acceptable comfort of occupants and residents in the process of reducing operational energy use of buildings.

In principle, the system collects and sends the energy use data and environmental data in every minute

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basis because the authors anticipated that some of the affecting factors could act on short duration of time.

One of the challenges for feasibility and reality of the system shown in Figure 1 was the harmonization of different protocol of used equipment. The authors have enhanced connectivity and interoperability among different protocols by inventing and installing converters that can 'interpret' signals by different protocols.

The system aggregates the collected data and makes the presentation to stakeholders of building, respecting on concerns of stakeholders. Those presentations give benchmarking. They also generate incentives for understanding and commitment by stakeholders.

Upgraded functions: Analysis to identify waste and inefficiency in operational energy use of buildings

Accumulation of every-minute data could provide sources of information for knowledgeable professions to identify waste and inefficiency in operational energy use of buildings. For example, the system has assisted to identify wastes and inefficiencies such as;

- too much mechanical ventilation compared with required indoor CO2 content
- too much use of artificial lighting compared with required level of illumination
- misuse of ventilation that restrict night-purge
- too sensitive sensors of equipment that restrict stable operation

Figure 2 exemplified identified unreasonable inefficiency. The vertical axis of the figure represents system-COP of chiller while horizontal represents output energy. Here, system-COP is the produced cooling capacity that is divided by total input energy. The optimum system-COP is 0.78. However, real system-COP is maxim=0.8, average=0.44. The fact suggests that system-COP of is quite low compared with optimum value, probably because the chiller is operated mostly in low efficient due to partial load (Sako et. al. 2010). The fact suggests the necessity and the way to improve the operation of the chiller by any means.

Advanced function: Feedforward operation control of building services and equipment

Further accumulation of energy use data and related environmental data provide the hint to construct energy demand anticipation model by assuming of the statistical relation between a set of environmental/operational data (input) and energy use data (outcome).

Figure 3 presents the outline of heuristic process on how the system would continuously upgrade the assumed energy demand anticipation model. Knowledgeable profession set up the assumed anticipation model. The user of the analytic function of the system identifies waste and inefficiency.

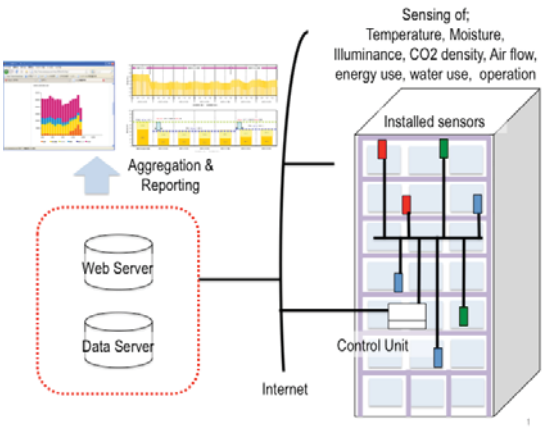


Figure 1 Sensing operational energy use and related environmental condition

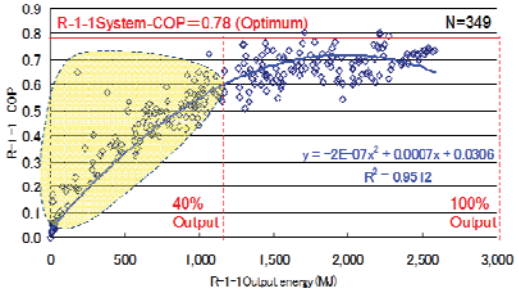


Figure 2 Example to identify waste and inefficiency in operational energy use of buildings: unbalanced output energy and system-COP

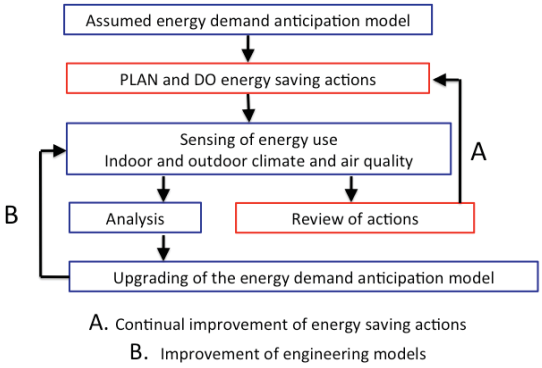


Figure 3 Heuristic process to upgrade energy demand anticipation model and a set of energy saving actions

Accordingly, the user takes some counter measures as 'Plan and DO energy saving actions'. Then, the user reviews the effect of the actions by energy monitoring function while the user concurrently analyzes and assesses the preciseness of energy demand prediction. The user revises the counter measure actions, as well as assumed energy demand anticipation model, and the user investigates further set of actions.

By repetition of such processes, the system could continuously upgrade the assumed energy demand anticipation model and the set of counter measure actions.

In case that the system successfully upgrade the assumed energy demand anticipation model, energy use in the near future could be predictable by parameters given by the weather forecast and previous records of occupants' and users' behaviour. It enables feedforward operation of building services and equipment.

For example, the authors have developed and applied such heuristic methods to small scale retail shops, convention centres, accommodations an office buildings (For example, Sako et. al. 2011).

EXPERIMENTAL ZERO ENERGY BUILDING IN THE UNIVERSITY OF TOKYO

In Japan, zero energy building is defined as "A building that consumes zero or nearly zero energy on an annual net basis by reducing primary energy consumption in the building through enhanced energy efficiency performance of the building envelope and facilities, networking of neighbouring buildings, on-site utilization of renewable energy, and so on." (METI 2009)

The authors had the opportunity to commit in the experimental pilot project to design and construction of zero energy building in Komaba campus, Komaba Centre for Educational Excellence (KOMCEE), which is one of the three major campuses of the University of Tokyo. It has five floors and one underground level floor. The total floor area of the building is 4,477m2. It includes several studios, convention rooms and meeting rooms.

Figure 5 illustrates a set of technologies applied in the building. It includes following technologies;

1. smart double skin cladding system by adaptively movable louvers (Figure 6 and Figure 7)
2. ground source heat pump system
3. radiation cooling/heating panel system
4. thermal storage utilization
5. natural ventilation by chimney effect
6. desiccant dehumidifier with exhaust heat from the heat pump
7. LED lighting system
8. Potable water saving including rain water utilization
9. photovoltaics (PV)
10. the smart energy management system

Some of the functions of listed technologies above are mutually dependent. For example, ground source heat pump supplies cool or hot water used in radiation cooling/heating panel system. Turning on/off of artificial lighting system, including LED has functional relevance with smart double skin



Figure 4 The elevation of Komaba Centre for Educational Excellence (KOMCEE) at Komaba campus in the University of Tokyo (see http://www.komcee.c.u-tokyo.ac.jp/)

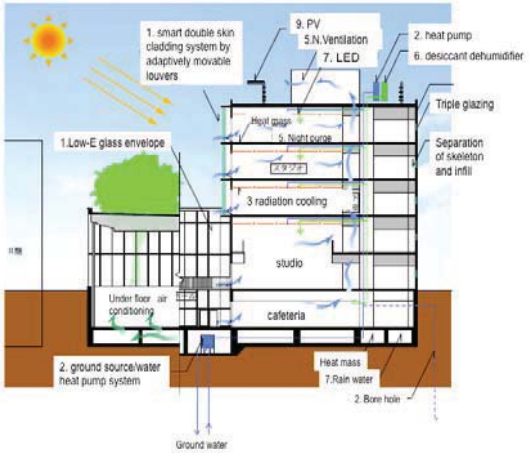


Figure 5 Technologies applied in KOMCEE

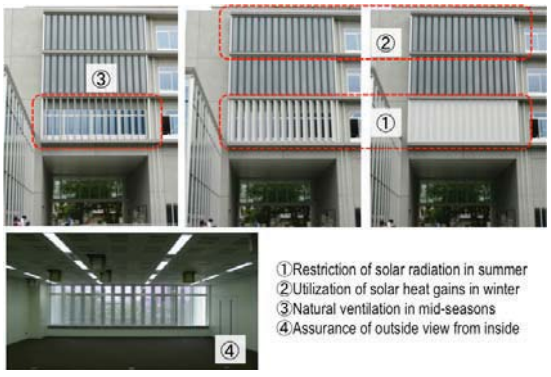


Figure 6 smart double skin cladding system by adaptively movable louvers

cladding system by adaptively movable louvers (Figure6).

Those three technologies need to be integrated by the smart energy management system and adaptable to work any of the following three modes as shown in Figure 7. Those are;

- Mode A: Mainly in the morning in summer, white coloured side of slat panels in movable louvers appears on the outside while the angle of louvers follows diurnal motion of the sun to prevent inclusion of sunrays to the inside.
- Mode B: Mainly in spring and fall, movable louvers are open to outside to maximize natural ventilation. If the outside temperature should be lower than inside in the night in summer, natural ventilation is introduced to facilitate night purge effect.
- Mode C : Mainly in the morning in winter (i.e. duration of time when sun altitude is relatively low), black coloured side of movable louvers faces outside in order to collect radiated heat from the sun and to stock them in the upper floor slabs by utilizing its thermal mass.

INTEGATED OPERATION BY THE SMART ENERGY MANAGEMENT SYSTEM

The installed smart energy management system has the function of energy monitoring system. Occupants and users can observe the real-time-based performance of operational energy use of the building as well as the related environmental conditions through the user interface shown in Figure 8.

At the stage of design of KOMCEE, design team members have agreed to facilitate participation and commitment of students in operation of the building because it is a good opportunity for students to build capacity to operate building intellectually. Consequently, the installed smart energy management system includes automatic control as well as manual control by immediate users. In order to facilitate commitment of students in operation, the authors organized a workshop with students and other stakeholders to raise positive concern. The workshop was also a good opportunity to review usability of the user interfaces.

Through the process shown in Figure 3, the smart energy management system has collected energy use data and related environmental/operational data continuously. The assumed anticipation model of operational energy use of the building has been upgraded through the heuristics process presented in Figure 3. The model is a basis for integrated operation.

Figure 9 illustrates the algorithm of decision-making tree for integrated operation by the smart energy management system. It aims to realize minimized stable operation of building services respecting on using spaces and active users captured by real time monitoring. The algorithm includes 'gates' of assessment and decision-making. It has the principle to maximize use of natural ventilation, daylights, thermal mass and heat gain in the building.

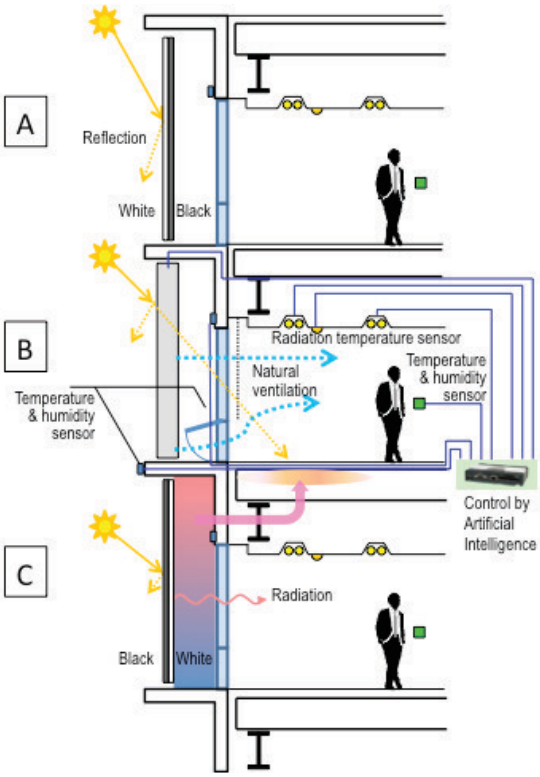


Figure 7 Expected three modes of operation around double skin cladding system



Figure 8 User interface for operation control installed in studio

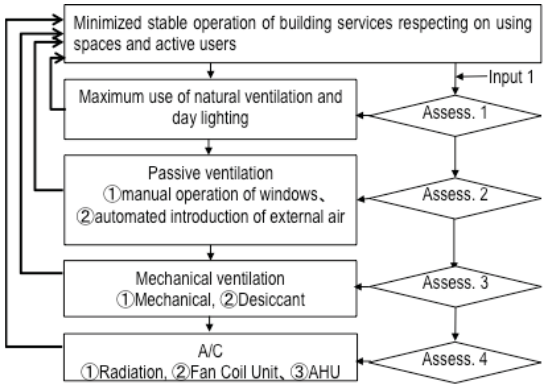


Figure 9 Decision-making tree for integrated operation by the smart energy management system

Here, data from the installed actinometers provides sources of information to judge current weather (i.e. sunny or cloudy). On cloudy days and rainy days, movable louvers of the double skin cladding system open to introduce natural daylight into the rooms, if external humidity is within the acceptable level.

In summer, time when direct sunrays do not reach studio, louvers open on the bright days. In the morning in winter, louvers turn to maximize direct gains by sunrays while louvers close when direct gains are not available.

The smart energy management system also includes the function to assess the occupancy of the rooms by motion sensors and other sensors. The assessment of the sensing facilitates automatic turning off artificial lights, and A/C.

In case radiation cooling/heating should be in operation, the angles of louvers of the double skin cladding are modified automatically to maximize the use of natural daylight. The system articulates the intensity of LED from 0 to 100% by automatically assessment on the sufficiency to the required intensity level of illumination.

The decision-making tree shown in Figure 9 provides the process of assessing the necessity and appropriateness of opening the windows, operation of mechanical A/C and night purge.

THE PERFORMANCE ACHIEVED BY THE SMART ENERGY MANAGEMENT SYSTEM

Initial scenario for net zero energy

Figure 10 illustrates the scenario toward zero energy building by 2030. The design team defined reference level at 1830MJ/m2/year as a standard reference level in comparison. Then the team aimed to reduce 35% from the reference level within three years since its start of operation. The inventory of the reduction is;

- 50% reduction in heating
- 30% reduction in cooling
- 20% reduction in lighting
- 20% reduction in clean water use
- 30000kwh/year (i.e. 1880GJ/year) generation by PV

Then the design team estimate another 20 % reduction no later than 2020 by proactive demand control and optimization by the smart energy management system. Furthermore, respecting on rapid improvement in efficiency of building services, another 20 % reduction by 2030 is supposed to be expected by replacement of existing equipment by those with higher efficiency in the future. In addition, conversion efficiency of PV would be doubled by 2030. Consequently, if those assumed conditions would be realized, the building could be net zero energy building.

Actual performance

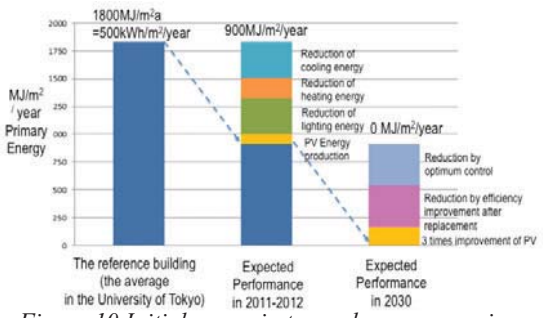


Figure 10 Initial scenario toward zero energy in 2030

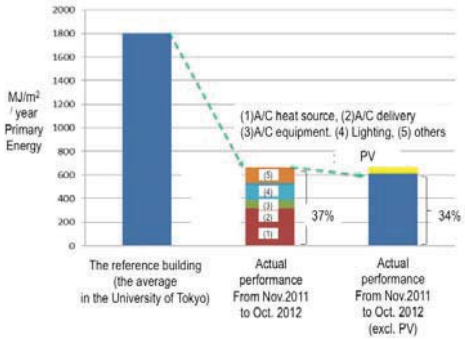


Figure 11 Actual performance achieved between 2011 and 2012

Figure 11 illustrates the actual energy performance between 2011 and 2012. Operational energy use of the building per m2 is 37% of the average of the buildings in the campus of the University of Tokyo. The actual performance of KOMCEE is far better than the initial scenario. The most influential factors for such better performance seem to be gains by ground source heat pump. However, it is appropriate to claim that integrated operation by the smart energy management system is also a significant enabler for such extraordinary saving of operational energy use in the building.

CONCLUDING COMMENTS

The application of the smart energy management system to the experimental zero energy oriented building proved the potential benefit and the effect of the system for saving of operational energy use without compromising environmental quality and comfort.

The achievement presented in Figure 11 is a consequence of effort in the first year since completion of construction. Respecting on lessons from previous examples of the application of the smart energy management system, the system would identify further waste and inefficiency in the following years.

The authors are continuously challenging for further improvement by upgrading of the smart energy management system. The authors have already

identified several issues to be improved in the algorithm and the method of sensing.

So far, commitment by users is not well diffused. Thus, the authors are planning to facilitate the commitment of occupants and other stakeholders. The author would appreciate having another opportunity in the future to report on further challenges.

This paper focuses on how the smart energy management system could contribute to improve performance of zero energy-oriented buildings. Zero energy buildings could be realistic by the integration of effective technologies. The paper only focuses on the smart energy management system among a set of technologies used in KOMCEE. The authors would present the effect of other technologies applied in KOMCEE.

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DEMONSTRATING APPLICATION OF ENERGY RESILIENCE ASSESSMENT MODEL

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ABSTRACT

Increasing frequency and severity of disturbances or disasters happening around the globe has affected energy security, architecture robustness and human activities. System performance including sustainability performance under such difficult time is a main concern of the concept of resilience. The objective of this paper is to demonstrate the application of a proposed methodology to assess the effect of demand response to energy resilience of community systems. This study defined energy resilience of a community as the ability of the community system depending on its own responsiveness and vulnerability to maintain its energy-dependent functionality throughout any disturbances. Based on this definition, an assessment model has been developed. The developed model was used in a case study to demonstrate its usefulness and applicability. Result of case study and implications of this proposed assessment methodology to real-world practice are discussed.

INTRODUCTION

Increasing frequency and severity of disturbances or disasters happening around the globe has affected energy security, architecture robustness and human activities. The critical problems of interest in this study are about: exploring the underutilized potential of demand response program of a smart grid system, exhibiting the importance of considering the interests of both supply and demand sides when making any studies or practices related to energy system performance, and examining the concept of resilience and its applicability in the discussion of human, architecture and energy. As a way of investigating the aforementioned problems, this study aimed to propose an assessment methodology to study the effect of demand response capacity to energy resilience of community systems based on bottom-up approach.

Objective of this paper

The objective of this paper is to demonstrate the application of a proposed methodology to assess the effect of demand response to energy resilience of community systems. I will explain the meaning of energy resilience and the process involved in proposing the methodology and developing the model to assess energy resilience. I will also make a case study to demonstrate the applicability of the proposed assessment methodology and discuss about it.

Methodology

I proposed an assessment methodology of system resilience after intensively reviewing literature related to resilience, assessment, system thinking, power grid systems and community. Then, I developed a model based on the proposed methodology to assess energy resilience of community systems. I also applied and adapted existing and well-established indicators, methods and models into my own assessment model. The case study was simulation-based and used actual measured data where possible and available in order to increase the realisticness of the case-study result.

PROPOSAL OF ASSESSMENT METHODOLOGY

After intensive literature reviews about resilience, system and assessment, I decided and proposed to have three frameworks to form the assessment methodology (*Figure 1*). The purpose of having a concept framework is to establish a fundamental and yet well-studied understanding of the concept of resilience and its attributes, and the emergence of resilience property in a system. The concept framework then becomes the reference and basics to the other frameworks. The indicator selection framework serves as the guideline to select indicators for the assessment. Maclaren presented a well-structured process to select sustainability indicators (Maclaren, 2007) and I proposed to follow Maclaren's method to select assessment indicators. The analysis framework is a necessary part of the assessment methodology because it explains the analysis, modeling and simulation methods to be used for assessing the resilience performance of a system during the stage of planning and designing, and for making a scenario analysis.

The proposed assessment methodology is generic. It was used to develop a model specific to assess the energy resilience of community systems which is explained later in other section.

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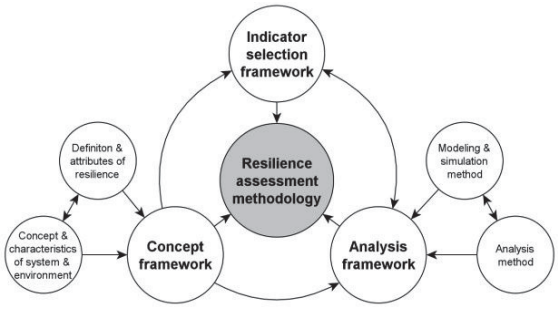


Figure 1 Structure of assessment methodology

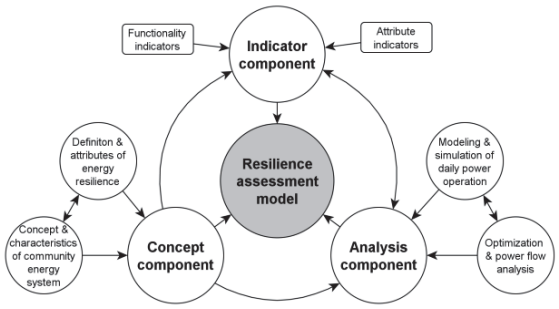


Figure 2 Structure of assessment model

Resilience

The concept of resilience is very broad that it spans over various fields of study. After reviewing literature of resilience and analysing several resilience definitions, I came up with my own view of the concept of resilience. I define resilience as *the ability of a system depending on its own responsiveness and vulnerability to maintain its system functionality throughout any disturbances*. I also attempted to distinguish resilience from other similar concepts or system properties (Chew, 2012). When the concept of sustainability emphasizes on system performance to achieve efficient use of resources without compromising the environment quality, the concept of resilience focuses on system performance to survive and sustain functionality during time of disturbances (Chew & Yashiro, 2013).

This proposed resilience definition is highly based upon when selecting assessment indicators and deciding whether a system is resilient or not. Under this proposed definition, a system is considered as resilient for as long as the system can maintain its significant system functionalities above minimum level. Responsiveness and vulnerability are two supporting system properties in expressing system resilience that the responsiveness supports but the vulnerability harms the system ability to maintain its significant functionalities. The responsiveness and vulnerability levels of a system provide an indication of the future system performance.

DEVELOPMENT OF ASSESSMENT MODEL

I developed an assessment model based on the proposed assessment methodology with the objective to assess the effect of demand response to energy resilience of community systems (*Figure 2*). The structure of assessment model follows the structure of assessment methodology. The three frameworks were further developed into three components that are used to specifically assess energy resilience of community systems.

Concept component: Energy resilience of community systems

Based on the proposed resilience definition, I defined energy resilience of a community system as *the ability of a community depending on its own responsiveness and vulnerability to maintain its energy-dependent community functionality throughout any disturbances*. Inherently, an important condition to ensure satisfactory performance of energy-dependent community functionalities is the balance of energy demand and supply, or power balance of the community system. This study considers that the performance levels of energy-dependent community functionalities can only be assessed when power balance is successful.

The community system in the assessment is town-level community system including its energy-related components: power generation, network and consumption components. I selected town-level community because it has the optimum size to function as a microgrid system that is an essential factor in the study of resilience of power grid systems. In systems thinking, there are reductionism and holism. I applied the concept of reductionism in this study that a system is equal to the sum of its parts, and the limited knowledge and ability of human to explain everything are the reasons why inequality occurs between a system and the sum of its parts. Under this reductionistic thinking, I adopted a bottom-up approach for the assessment that a community system represents the top level and buildings within the community area (as power generation and consumption components) represent the bottom level.

Demand response

Demand response (DR) is defined as changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized (U.S. Department of Energy, 2006). DR is a feature of smart grid systems that can change the norm of relying only on supply side to achieve power balance (to meet growing demand), into integrating efforts and contributions from both supply and demand sides to achieve power balance

and optimize power operation. The objective of developing the assessment model is to study the effect of DR to energy resilience of community systems.

Power utility companies can offer various types of DR programs but the working principle is the same that incentive is given to customers who fulfil the request when a DR event is initiated. However, the implementation methods can be a crucial difference that some companies may use DR program to achieve desired demand pattern by imposing different pricing rules to customers, but other companies may treat the customers' power demand as a virtual source of power supply [伊藤, 2012]. This study applied the latter implementation approach. Under this approach, customers' convenience (comfort, productivity, etc.) in consuming energy is ranked at higher priority over economy and efficiency factors of a power operation that customers are only asked to reduce their power consumption when power balance is at risk.

Indicator component

I decided to assess energy resilience of a community system based on the performance of daily power operation of the community system. Adhering to the proposed resilience definition, resilience performance depends on the achievement of community functionalities that it is represented by functionality indicators (*Figure 3*). I have selected power balance of daily power operation as the primary functionality indicator, and two significant community functions: demand users' convenience and cost of electric energy as the supporting functionality indicators. The mathematical expression of demand users' convenience (FT2) is:

$$FT2 = \sum_{t=0}^{23}\sum_{c=1}^{Nc} dm_{ct} \,/\, \sum_{t=0}^{23}\sum_{c=1}^{Nc}(dm_{ct} + dr_{ct}) \quad (1)$$

where dm_{ct} is the actual demand (post demand response event) of consumption component c at time t, dr_{ct} is the demand response capacity contributed by consumption component c at time t, c represents consumption component unit, N_c is the total number of consumption component units, and t is time unit in hour. And the cost of electric energy (FT3) is:

$$FT3 = (\sum_{t=0}^{23}\sum_{g=1}^{Ng} cs_{gt} + \sum_{t=0}^{23}\sum_{c=1}^{Nc} cs_{ct})/ \sum_{t=0}^{23}\sum_{g=1}^{Ng} sp_{gt} \quad (2)$$

where cs_{gt} is the cost of electric energy supplied by generation component g at time t, cs_{ct} is the cost of demand response capacity committed by consumption component c at time t, sp_{gt} is the power supply of generation component g at time t, g represents generation component unit, and N_g is the total number of generation component units. Each indicator will be compared to its own benchmark or target performance value. When the primary functionality indicator (power balance) underperforms, then the community system is considered as unresilient that no further assessment of the performance of other indicators is made. When a power operation fails to achieve power balance, the possibility of the relevant system to experience power outage is increased. Otherwise, the performance of the supporting functionality indicators is checked to determine whether the community system is resilient or not.

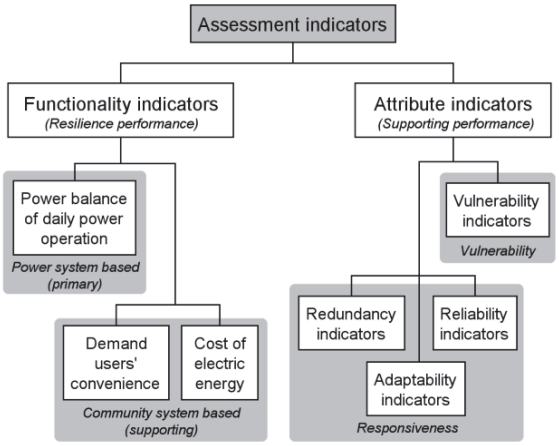


Figure 3 Categorization of proposed assessment indicators

Energy resilience depends on community functionalities and energy-dependent community functionalities depends on the responsiveness and vulnerability of power components in the community system. When the responsiveness and vulnerability levels of power components (generation, network and consumption) may not directly express the energy resilience, I decided that it is necessary and significant to include them into the assessment because they can provide an indication of the future resilience performance of the community system. Each power component is assigned with attribute indicators to assess its responsiveness and vulnerability performances. I selected redundancy, adaptability and reliability to represent responsiveness performance because they are among the attributes most influential to resilience performance. In this study, I defined that *redundancy* is the remaining and unused capacity of a component or system which can be used to achieve power balance, *adaptability* is the remaining and unused capacity of a component or system which can be used almost instantly when it is needed to achieve power balance, *reliability* is the ability of a component to continue to perform its intended function to achieve power balance, and *vulnerability* is an internal risk factor that the exposed component may be affected by the phenomenon that characterizes the hazard to disturb power balance. Each power component is assigned with its own set of attribute indicators and the principle of deriving mathematical expression of the indicators is the same across all the power components.

I have tried to propose and tested some assessment indicators (Chew & Yashiro, 2013). The assessment indicators are selected primarily from variables related to power capacity because power capacity is an important factor in a daily power operation and is easily comprehensible to the non-professional target audience. After testing and refining the selection of indicators, I decided to apply and adapt existing and well-established indicators into my developed model.

Analysis component: modeling

An assessment tool is usually used to assess the performance of a system based on past and actual results or data. When performances of a system in planning or design stage, or in different scenarios or situations are to be investigated, one can model the system and make simulations to do it. The analysis component serves as a guideline to model a community system and make simulation of the daily power operation of the community. The result from the analysis model is used to assess the performance of energy resilience of the community (*Figure 4*).

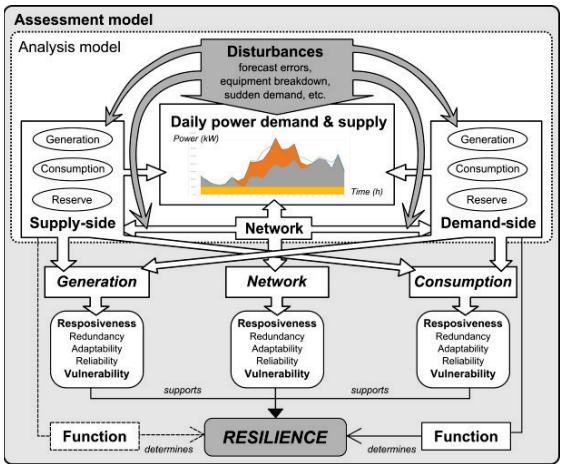


Figure 4 Analysis model as part of assessment model

A complete series of daily power operation starts by forecasting the power demand, scheduling power generation plan to meet the forecasted demand, and when the daily power operation begins, ancillary services are dispatched to achieve power balance until the operation ends (*Figure 5*). The modeling of town-level community systems becomes the first step to model the power demand of a community system. Essentially, the modeling process is based on bottom-up approach that a town-level community is modelled from building level (*Figure 6*). In between building level and town-level community system, there are also neighbourhood and village levels. A building can be a power generation or consumption component, or both together. It is important to note that a building as a consumption component also serves as a source of demand response capacity. Power supply sources including demand response capacity and power demand sources are modelled from the bottom level to simulate the daily power operation of the top-level community system.



Figure 5 Series of operations in a daily power operation

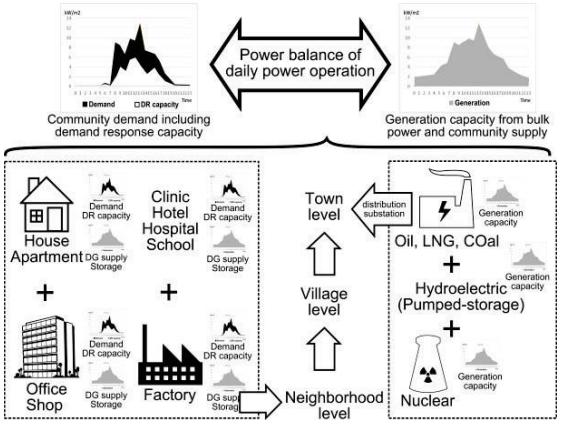


Figure 6 Bottom-up approach in modeling community systems for making simulation of daily power operation

I considered seven building types in a community. The power demand of a community system is the total power demand of all the buildings types. Power demand of a building type is modelled by firstly summing up all of its unit demands per building floor area (BFA) for energy uses such as heating, cooling, hot-water making and electric appliances, and then multiplying the total with the BFA of a building type (*Figure 7*). Regarding on the modeling of demand response capacity of each building type, as there is no available and reliable statistical information, my best effort is to estimate it as the percentage of ongoing power demand of a building type that the building user is willing to turn off when requested. This willingness (percentage value of demand reduction) is dependent on the peak status and significance of building function. For example, an office building is less willing to reduce demand than a residential building because of productivity factor, and a hospital, data centre or fire station usually has lower demand response potential because of their significant functions. This estimation approach is very similar to modeling power demand that demand response capacity of a building type is estimated from the unit demands per BFA for energy uses and then they are summed up together to form the maximum demand response capacity of the building type.

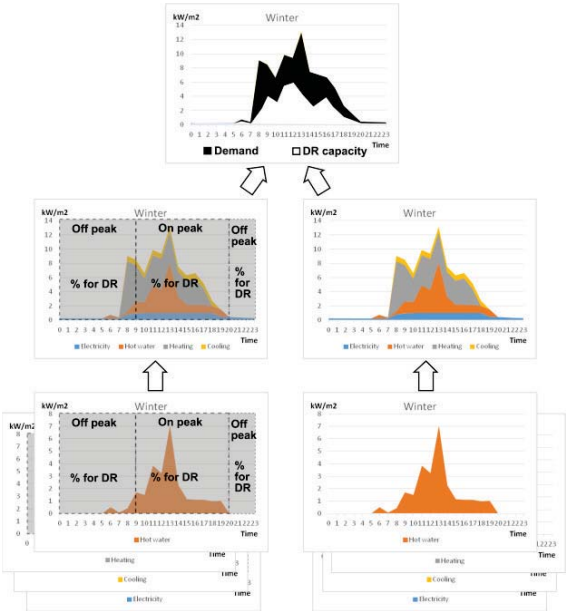


Figure 7 Bottom-up approach in modeling power demand and estimating demand response capacity of a building

In this study, all building types are envisioned to be equipped with advanced metering infrastructure like smart meters, electric appliances controllable by remote demand response aggregators or power utilities companies and other necessary equipment required for demand response operation. As mentioned earlier, customers' convenience (comfort, productivity, etc.) in consuming energy is ranked at higher priority over economy and efficiency factors of a power operation that customers are only asked to reduce their power consumption when power balance is at risk. In addition, a user has the rights to choose whether to fulfil the request when a demand response is initiated that this human factor is modelled with probability-based method in the analysis.

There are three kinds of power generation components: stable, intermittent and storage-based generations. A stable generation component is represented by the bulk power supply of a community, which consists of various types of power plants. In reality, it is almost impossible to keep track of the sources of bulk power supply delivered to a certain area but I decided to take into consideration of the sources of bulk power supply in the analysis and assessment because power plants with different characteristics have different influences to the performance of a power operation. Solar energy generation by photovoltaic panels represents the intermittent generation that it is modelled from village level. Actual data of solar generation efficiency and output, and actual rate of feed-in tariff announced in the year of 2013 were used in the analysis. The third type is the storage-based generation components which function as power supply sources in day time but power demand sources in night time. The storage-based generation component within a community, such as a battery storage is modelled from village level, but the pumped-storage hydroelectric from the supply side is modelled at town level because it is part of the bulk power sources.

Analysis component: simulation

In the simulation of daily power operation of a community system, demand response capacity is used as the decision variable to examine the effect of demand response capacity to energy resilience of community systems (*Figure 11*). When optimizing the scheduling process and dispatching of ancillary services in a daily power operation, the objective function is to minimize the cost of electric energy. General constraints of a power operation including power balance, ramp rates of generators, minimum generation are considered in the optimization. After running a successful simulation, power flow analysis is used as a means to verify the feasibility of the simulated result and obtain the power flow of the network component. Finally, the analysis result is used to assess energy resilience of the community system based on its daily power operation performance.

Verifying and validating the analysis model are to a limited extent equal to verifying and validating the assessment model itself. While verification could be made, the validation of the assessment model was not feasible at the time of this study was made because the required information was not available or disclosed.

DEMONSTRATING APPLICATION OF ASSESSMENT MODEL THROUGH CASE STUDY

In order to demonstrate the effectiveness of the proposed methodology in studying the effect of demand response to energy resilience of community systems, I made a case study by using the developed assessment model. I selected Umegaoka town in Setagaya district of Tokyo as the community system (*Figure 8*). Umegaoka town is highly composed by residential buildings (85%).



Number of villages	3
Number of neighborhoods	115
Town area (km2)	0.51
Buildable area (km2)	0.46
Built area (km2)	0.28

Figure 8 Profile information of Umegaoka town

Disturbance scenarios and demand response capacity

The concept of resilience focuses on system performance to survive and sustain functionality during time of disturbances. Various disturbances can happen to a community system. However, this case study only considered and focused on disturbances happen to the stable generation component (the bulk power supply). This condition could also provide insight of the ability (energy resilience performance) of the Umegaoka town to function as a self-supported microgrid in the occasion where bulk power supply is interrupted or disturbed. Five disturbance scenarios were prepared that disturbance scenario DS1 represents normal scenario where all stable generation units are working properly and disturbance scenario DS5 represents the emergency scenario or worst-case scenario where all stable generation units are working at half of their maximum rated capacities. The other disturbance scenarios (DS2, DS3 and DS4) are the interpolation of the normal and emergency scenarios.

In order to study the effect of demand response capacity to energy resilience of the Umegaoka community system, five levels of demand response capacity were prepared and applied in each disturbance scenario. Level DRC100 represents the ideal level that the demand response capacity which building users are willing to contribute is at maximum level. It is important to note that as building users have their minimum power demand and therefore the maximum power demand a building user is willing to cut is usually less than the total power demand. Furthermore, some building users can opt to ignore the demand response request. On the other hand, level DRC000 represents the situation where demand response capacity is zero or no implementation of demand response at all. Other levels (DRC075, DRC050 and DRC025) are the interpolation between the ideal and zero levels. The preparation of these five levels of demand response capacity was based on extreme conditions that the analysis adopted the *possible* design, instead of *representative* configuration of demand response capacity of a community.

RESULTS OF CASE STUDY

Resilience of a system is not a fixed or permanent state but changes according to the system performance during a specific disturbance event. *Table 1* shows the analysis results of the Umegaoka community system under five disturbance scenarios and five levels of demand response capacity. "OK" means that power balance was achieved and assessment of the performance of other indicators continued, and "FAIL" means otherwise that the Umegaoka community with the specific level of demand response capacity under the specific disturbance scenario is unresilient because unsuccessful power balance is a possibility to blackout and is expected to affect community functionalities significantly.

Table 1 Performance of primary functionality indicator

DISTURBANCE SCENARIO	LEVEL OF AVAILABLE DEMAND RESPONSE CAPACITY				
	DRC 100	DRC 075	DRC 050	DRC 025	DRC 000
DS1	OK	OK	OK	OK	OK
DS2	OK	OK	OK	FAIL	FAIL
DS3	OK	OK	FAIL	FAIL	FAIL
DS4	OK	FAIL	FAIL	FAIL	FAIL
DS5	FAIL	FAIL	FAIL	FAIL	FAIL

When power balance was successful in a scenario, the performance of supporting functionality indicators was assessed to determine if the Umegaoka community in that scenario was resilient or not (*Figure 9*). Based on my proposed methodology and resilience definition, the Umegaoka community system is considered as resilient so long as its community functionalities meet the minimum benchmark or target performance. The plane surface spanning across the bars in each graph is for demonstration purpose that it represents the minimum benchmark performance. The minimum benchmark performance can be determined through discussion among key stakeholders of the community system. Demand users' convenience in all scenarios exceed the target performance but the cost of electric energy could not meet the target performance in scenario DS3 and DS4 that the Umegaoka community in those scenarios is considered as unresilient because the cost of electric energy is higher than target value. *Table 2* shows the final performance of energy resilience of the Umegaoka community after considering the performance of all functionality indicators. "OK" means that the Umegaoka community was resilient in that specific scenario and "FAIL" means otherwise.

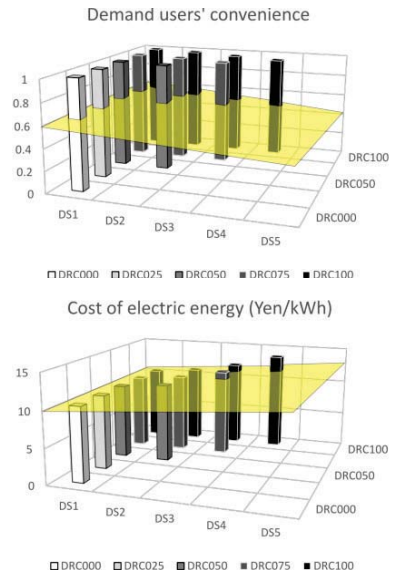


Figure 9 Performance of supporting functionality indicators

Table 2 Performance of energy resilience of Umegaoka community

DISTURBANCE SCENARIO	LEVEL OF AVAILABLE DEMAND RESPONSE CAPACITY				
	DRC 100	DRC 075	DRC 050	DRC 025	DRC 000
DS1	OK	OK	OK	OK	OK
DS2	OK	OK	OK	FAIL	FAIL
DS3	FAIL	FAIL	FAIL	FAIL	FAIL
DS4	FAIL	FAIL	FAIL	FAIL	FAIL
DS5	FAIL	FAIL	FAIL	FAIL	FAIL

The performances of attribute indicators of power components can provide an indication of the future resilience performance of the community system. *Figure 10* shows the performance of attributes indicators of power consumption component. Target performance of each attribute indicator for each power component should be determined in the way that any underperforming attribute indicator should represent a sign that the community system is may become unresilient in the near future if no any improvement measure is taken.

DISCUSSION

The result of the case study shows that a community system with more demand response capacity can be more resilient in the aspect of the performance of energy-dependent community functionalities. When a disturbance happening to a community is more severe, the demand users' convenience decreases because more demand response capacity is needed to ensure power balance, and the cost of electric energy increases because more demand response capacity (whose cost is set higher than other power supply sources) is needed. It is important to note that under my proposed methodology, the increase or decrease of the performance of functionality indicators cannot tell if the resilience performance is increased or not. However, as long as the performance of functionality indicators (community functions) can meet the minimum target performance in any given disturbance scenario, then the community system is considered as resilient.

It is necessary to discuss the pros and cons of using demand response capacity as the decision variable to study energy resilience. The impression of the usefulness of demand response can be quite different depending on how demand response program is implemented. Under the implementation principle used in this study that customers are only asked to reduce their power consumption when power balance is at risk, the usage of demand response is limited to fill up the insufficiency of power supply that it is hard to exhibit the advantage or disadvantage of having a little or abundant of demand response capacity. This is why the performances of supporting functionality indicators are equal for all levels of demand response capacity in a specific disturbance scenario. The effect of demand response capacity only becomes more apparent when system performances in *different* disturbance scenarios are considered and compared. If demand response is implemented differently, for example, it is also used to achieve more efficient and economic power operation, then the usage of demand response in a power operation will become more flexible and diversified. Such changes can affect the overall analysis and assessment results and the performance of supporting functionality indicators in a given disturbance scenario is expected to vary with different levels of demand response capacity.

Usefulness and limitation

The usefulness and limitation of the proposed assessment methodology and the developed model must also be discussed. Inherently, the developed model can be further refined to be used by various stakeholders including decision makers in analysing and improving energy resilience of community systems. I have proposed to include the supporting performance indicators (attribute indicators) into the assessment and this assessment is made to each power component of the community system. This proposal can help to easily detect which component is underperforming and restricting the resilience performance of the whole community system, and provide an indication of the future resilience. I also have proposed that energy resilience assessment should not only focus on supply-side functionalities, but similar consideration must be given to demand-side fucntionalities as well because while one can conceptually obtain a better performance by optimizing system operation with one-sided consideration, an optimization taking into consideration of needs and requirements of all sides is more realistic and workable solution.

The current state of the developed model can only assess if a community system is resilient or not but cannot show the degree of resilience performance or unresilient performance. The proposed assessment indicators are mainly intended for the use to demonstrate the proposed assessment methodology that I selected them by adapting or directly applying well-established indicators. While these indicators are not wrong, they may be too simple and basic to be used for practical purpose.

CONCLUSION

I have proposed a methodology and developed a model to assess the effect of demand response to energy resilience of community systems. The proposal and development of assessment methodology and model were explained in detail. Then I made a case study by using the developed assessment model to assess the energy resilience of the Umegaoka community. The case-study result shows that a community with more demand response capacity is

more resilient because it has a higher chance to achieve power balance when experiencing sever disturbance situation. Discussion of the applicability and limitation of the proposed methodology was made as well.

ACKNOWLEDGMENT

I am indebted to Prof. Yashiro for providing me his guidance, advices, trainings and opportunities all these years. I am also grateful to Dr. Yanagihara and Prof. Horita for their constructive and valuable opinions, critics, suggestions and ideas for my study.

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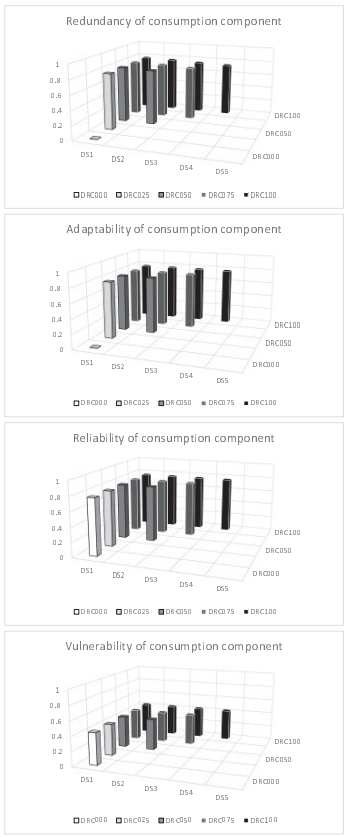


Figure 10 Performance of attribute indicators of power consumption component

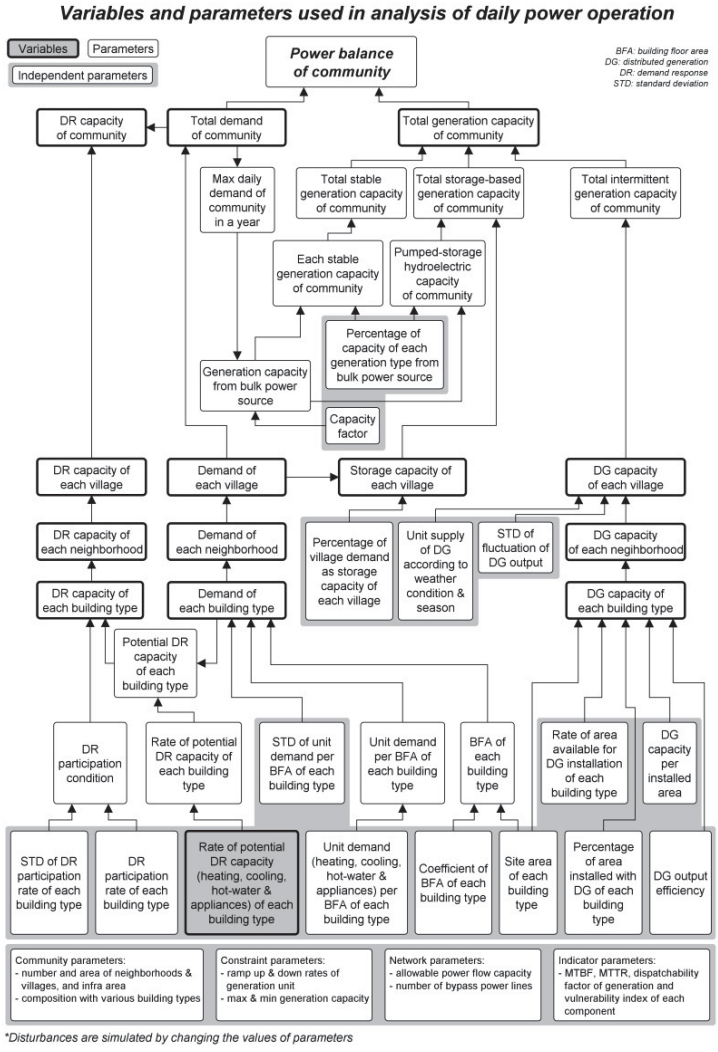


Figure 11 Variables and parameters used in analysis model

DESIGN FOR TROPICAL NORTHERN AUSTRALIA MENZIES SCHOOL OF HEATH RESEARCH

Keith Savage
Hames Sharley, NT Australia

ABSTRACT

This report presents the process undertaken for developing an architectural design for a project located in the extreme and contrasting tropical climate of Darwin, Australia.

Darwin is a unique environment in that it endures both intense heat and humidity and yet has dry, and waterless extremes throughout a large part of the year. As such, the usual approach of designing for a hot and wet tropical climate does not apply. Instead, the principles outlined in this report must be adopted and applied in a tailored approach in order to create both a practical and appealing design solution for this environment.

The humidity in the Top End of Australia is tremendously high up to 75% to 85% for a large part of the year, except for a short period of only three to four months during the middle of the year.
It rains heavily for approximately four months each year, whereas for the remainder of the year, it is fundamentally dry and barren.

The region experiences extremely high UV levels throughout the whole year, which are some of the highest in the world.

In this climate hot-days are not followed by cool-nights, and buildings are not allowed to passively cool down. For this environment, the temperature average during the day only varies a maximum 3-4° C over the whole year.

Designing a modern, commercial building which is both practical and appealing to the end consumer is the challenge particularly with a western Anglo-Saxon focus.

The two new buildings for the Menzies School of Health Research at Charles Darwin University (CDU) and Royal Darwin Hospital (RDH), consist of new office spaces, the refurbishment of laboratories, clinical research areas, new meeting/teaching spaces, an auditorium, public foyers, and dining spaces – and the client wanted an environmentally friendly and indigenously sensitive solution.

INTRODUCTION

Darwin is the only Australian capital city located within the Tropics and which also directly interfaces with Asia. Darwin‟s closest major populations are not within Australia itself, but are in fact Indonesia, Timor and Papua New Guinea.

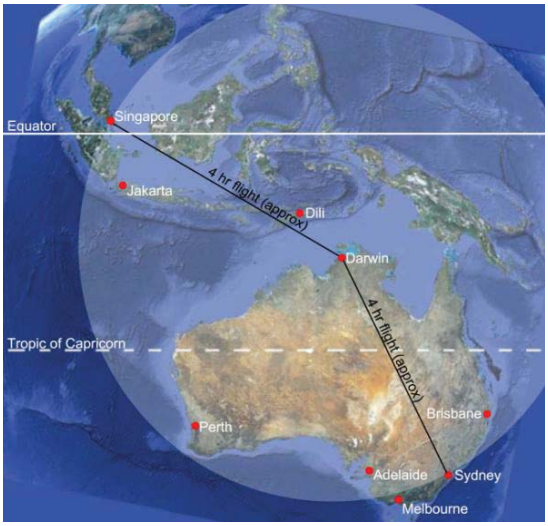


Figure 1 Australia in Context

The Darwin/Top End climate is stereotypically described as „hot, humid and muggy‟, with the vast majority of Australians choosing to live in the cooler, Southern states. By geographical location, the region falls under the influence of the north-west monsoon and is also considered on the edge of Australia‟s arid interior.

The Wet season brings heavy, monsoonal downpours, which generally commence around November/December and continue through to March/April. Rainfall of up to 1.8.m is not uncommon during the Wet season. Cyclonic activity in the region also accompanies this annual monsoon.

The May – October Dry season is the other extreme to the Wet Season where there is only the bare minimum rainfall and strong wind patterns.

During the Wet season, prevailing winds come from the North-West and in the Dry season, from the South-East.

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Darwin is located at latitude 12.5°s which is closer to the equator than Bangkok. Seasonal temperature varies from a daily maximum of approximately 35° to 32° C with severe lows consequently minimal. The sun path during the year falls to the North and South of a given location. The diurnal (day/night) temperature variation, relative to temperature also minimal which is different from Arid Australia.

Accompanying the climatic elements of the natural Top End setting is a landscape shaped by these schizophrenic weather patterns. During the Wet season plant life blooms gangly and green, whilst during the Dry season the greenery dries out creating an environment where fires thrive and pooled water drains into underground reservoirs and billabongs. The hard, barren flood plains formed during the dry season affects the bondage between water and land during the next wet season, creating mass flooding.
The environment during the Dry can be hazy and smoky due to the high levels of dust and fires. To escape this harsh environment, wildlife retreats to the billabongs, rainforest and gorge areas where microclimates within the landscape provide protection from the heat and dryness.

The Darwin lifestyle is extremely relaxed compared to other Australian cities, particularly the Southern capitals. The climate heavily influences dress and lifestyle choices for Darwin residents. An enjoyment and appreciation of the outdoors is typical of the local population, with camping, fishing, boating, sports and BBQ‟s being popular pastimes.
The dress code is also relaxed and casual, with a strong emphasis on comfort as opposed to fashion in order to accommodate the relentless heat and humidity; especially during the Wet season. This dynamic even applies within the workplace, with men generally wearing neat tidy clothing with open neck shirts, no jackets or ties; and women wearing loose/light free falling dresses, tops and skirts or trousers.

Menzies School of Health Research has been located in Darwin for approximately 25 years and is the only major Research institution located in the Australian Tropics. It is an organisation of approximately 300 people and is principally involved with research relating to tropical diseases and indigenous health. Menzies in Darwin is closely aligned to both Charles Darwin University (CDU) and the Royal Darwin Hospital (RDH).

The Menzies project consists of the development of two projects at both CDU and RDH and consists of the development of;

- New office space
- Refurbishment of existing laboratories
- New meeting/teaching spaces
- Clinical research areas
- A 250 seat auditorium
- Public foyers
- Dining/Staff spaces.

This projects value is approximately $50m. From a corporate perspective, both projects are required to have similarities in design so that employees and clients felt they were involved with the same institution, as opposed to transitioning through various institutions, providing an all-encompassing experience. The client wished for very environmentally friendly projects.



Figure 2 Menzies Site CDU (Charles Darwin University)



Figure 3 Menzies Site RDH (Royal Darwin Hospital)

SIMULATION

To determine the client‟s objectives for the project, a workshop was conducted which formulated the brief and key project drivers, as indicated;

Architectural Language

- A refined contemporary „Top-End‟ architecture
- A design based on the principles of tropical architecture, combined with detailing that

represents Menzies as „a research organisation that has „come of age".
- Connection to landscape.
- Simplicity
- Simple layouts (with a strong layout that is clearly derived from site analysis).
- Structure – layouts derived from efficient structural design.
- Materiality – light weight – steel structure/glazing/cladding.
- Dappled light - weaves

Vision – Briefed Drivers

- Both buildings are to be iconic buildings that make a statement about Menzies presence on the site in a manner that is sympathetic to the adjacent buildings and gardens.
- The building needs to represent a research organisation that has „come of age".
- Open/welcoming/light – foyers should feel open and large with capacity for public exhibitions/functions.
- Design suited to the tropical environment.
- Provide indoor/outdoor spaces.
- Nominal five star or better design that provides a healthy internal and external environment for Menzies" clients, staff and contractors; reducing whole of life impacts of buildings.
- Good way finding
- Designs that encourage the use of stairs – which could be a feature used for public address.
- Flexibility.
- Indigenous friendly – the facilities are to create a welcoming environment for Indigenous people – an integrated approach rather than isolated pieces of art.
- Design and interiors that reflect the breadth of Menzies work, the regional variations and international relationships (Indonesia, East Timor and the Pacific) – ensure that all visitors have an appreciation of the communities that support Menzies in undertaking research.
- Social Space – "the most productive and successful scientists are intimately familiar with both the substance and style of each other"s work"

    - Architecture that supports both structured and informal interaction, flexible use of space and sharing of resources.
    - Promoting use of atriums, stairs, built in window seats etc – design that provides opportunities for people to meet and exchange ideas.

Individual CDU Key Requirements

- Maximise the vista of the nearby Chinese Water Garden and access to the adjacent library.
- Two major avenues to entrance (towards the road/carp park on the other side, towards the rest of the University) that are equally importance and both should evoke the feeling of entering a building of substance.

Individual RDH Key Requirements

- A suitable area was required to accommodate large formal functions. This will be used for fundraising, profile raising and media events. It should offer at least two areas suitable for launches and TV interviews (with log backdrop/points of visual interest). The capacity to bring in school groups for science promotion and other flexible uses is encouraged.

Other

- Ongoing operational and maintenance costs of the facility must be catered for and reduced where possible.

DISCUSSION & RESULT ANALYSIS

Response to Client Brief

Hames Sharley"s response to the Client Brief and project drivers was to develop an all encompassing set of ideas which would guide the project design.

A set of design principles was established for the project based on the following ideas;

- Cool People
- Cool Site
- Cool Building
- Cool Technology



Figure 4 – Menzies CDU Perspective

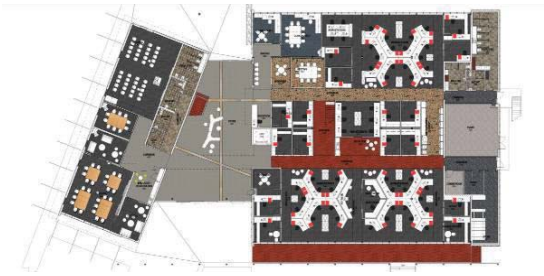


Figure 5 – Menzies CDU Ground Level

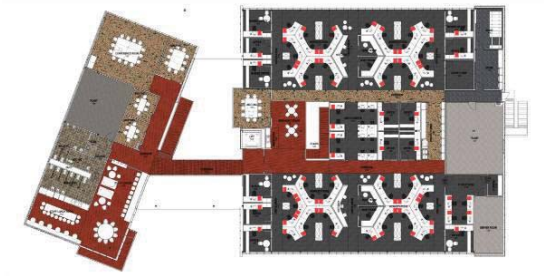


Figure 6 – Menzies CDU Level 1



Figure 7 – Menzies RDH Perspective

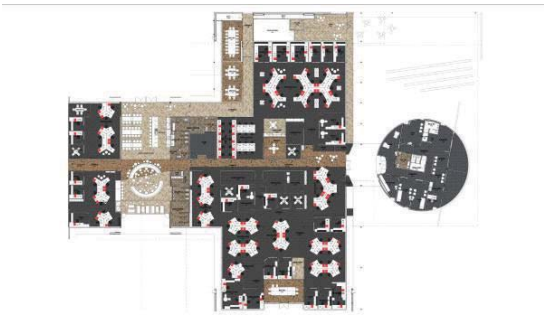


Figure 8 –Existing John Mathews Building RDH Partial Ground Level



Figure 9– Menzies RDH Ground Level (Extension off John Mathews Building)

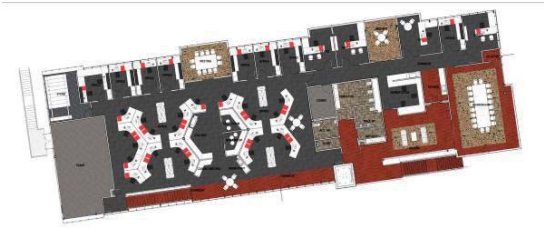


Figure 10- Menzies RDH First Floor Level

Cool People

- Darwin is a relaxed environment
- The people are experienced living with the temperature and humidity particularly the Indigenous population.
- The people dress accordingly
- Indoor/Outdoor spaces are important particularly those which are shaded.

Cool Site

- Strong emphasis and interaction with site landscaping, including the development of microclimates around perimeters of the building and courtyard spaces. Therefore, reducing the
- ambient temperature around the building edge.
- The introduction of water into the main courtyard space at .
- Use of landscaping to provide visual relief from interior of building and reduce external glare.
- Minimal maintenance-free materials onsite, ongoing labour and upgrading.
- Design of site to allow to building to be able to perform at its maximum capacity and the people using the building.
- Allow North/South orientation of building
- Shade

Cool Buildings

- Character of buildings to be distinctly Darwin
- Design to accommodate and relate to Indigenous people.
- Respond to climate

- Shading of building
  - Large Roof overhangs
  - Veranda spaces
  - Creation of transition zone between building and landscape (micro-climates)
  - Filtering of light/glare.

- North/South orientation maximised with predominately blank East/West walls. Glazing only located on North/South walls.
- Prominent entries.
- Creation of foyer spaces to act as main building circulation areas, however to also act as a large airlock.
- Heavily insulated walls and roofs, including double glazing throughout.
- Selection of glazing type to suit location and orientation of building (various types of glazing used throughout building rather than „one size fits all" approach).
- Large roof overhangs, particularly on North facade to maximise shading to all wall surfaces including glazing.
- Large floor plates, ensuring maximum building flexibility.
- Large areas of glazing, providing excellent visual connection to the outside.
- Maximise distance to glazing, eight metres from all internal areas.
- High ceilings to allow air circulation and maximum penetration of light, whilst also leveraging the feeling of open space.
- Lightweight construction (low thermal mass).
- High-quality and durable sealing of building, which included pressure testing of building envelope. This was done at construction completion to ensure air tightness of shell.
- Two storey only construction. This was to encourage staff interaction, minimising the use of lifts.
- Multiple staff areas, including meeting spaces, quiet rooms, tea and coffee rooms, lunch rooms, lounge areas, outdoor areas specific for staff. Many of these spaces have the capacity to be fully opened to the natural environment during the Dry Season.



Figure 11 Menzies CDU Landscape Plan



Figure 12 Menzies RDH Landscape Plan

Cool Technologies

The environmental sustainability has been examined for all building services, including mechanical/electrical and hydraulic systems. Testing and simulation of the design outcomes were critical for the creation of design solutions. Sound, responsible design has been applied to all these areas, however the standout issues in relation to this matter are the following:.

- The design of an innovative air conditioning system which controls Co2 levels of the air that is introduced via the air conditioning system to match occupant demand.
- Preconditioning of the outside air, utilising heat recovery exchanges (enthalpy wheel) which in turn, exhaust/return the air to precondition incoming air. Furthermore, generates active cooling of the incoming outside air to enable optimised and energy-efficient removal of excess humidity.
  Works in conjunction with the building shell design, where the shell is pressure sealed to ensure minimal intrusion to the humidity outside.
- A thermal recovery ventilation system reduces energy by cooling and dehumidifying the outside (fresh) air with the cool dry air that is exhausted from the building.

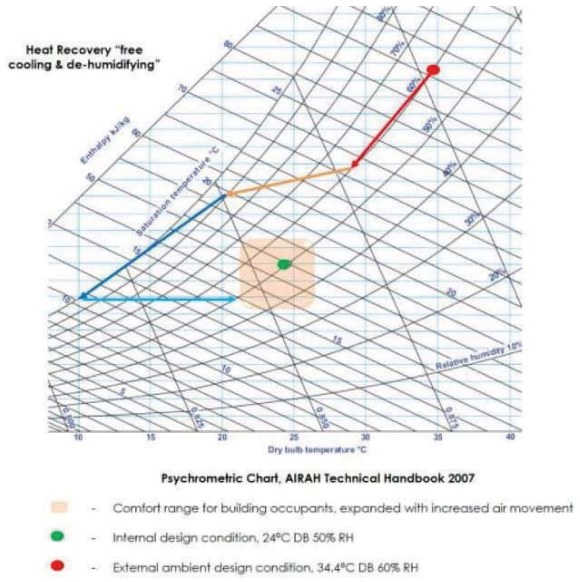


Figure 13 – Psychrometric Chart

- Provision of ceiling fans to increase air movement and directly cool occupants. This subsequently allows the air conditioning to operate at higher room temperatures, for

example 27˚ C in lieu of 24˚ C resulting in reduced thermal plant consumption.
Building occupants can control the additional airflow and as such, comfort levels are also increased. This is particularly pertinent with the change of seasons from Wet to Dry, where the space can be sufficiently cooled by either the ceiling fans only, or air conditioning only.

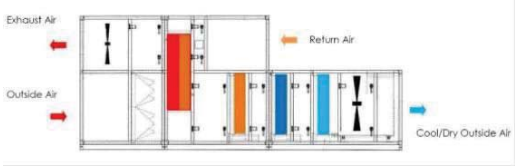


Figure 14 Schematic of Pre Conditioning Unit (PCU) and Heat Recovery

Over dehumidification of air conditioned spaces within tropical climates can lead to occupant discomfort due to draughts and over cooling.

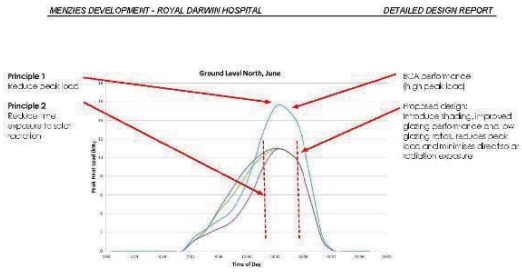


Figure 15 Peak Heat Load Graph – demonstrating effects of high performing facade

- The high level ceilings in conjunction with daylight harvesting ensures minimal use of the internal lighting systems.

TESTING OF PROJECT OBJECTIVES

So as to ensure the project would meet the project‟s objectives, a list of desired sustainability criteria were formulated as follows;

- All design elements were tested through project simulation at design stage to ensure the objectives were achieved.
  Building simulation, glazing areas and ratios, glazing performance, external shading devices, facade performance, 3D modelling.
- Nabers Energy Base Rating, exterior lighting, ventilation, cooling, pumps, common lighting.
- The project was not intended to register for a Green Star rating under the Green Building Council of Australia (GBCA); however the project team made strong commitments to deliver the project with sustainability initiatives and performance outcomes at a level that meets or exceeds an equivalent five star benchmark.

The sustainability objectives for the project are summarised as follows;

- Maximise internal environmental quality and occupant comfort/satisfaction.
- Reduce greenhouse gas emissions and achieve a five star Nabers Energy Rating.
- Reduce potable water consumption and achieve four star Nabers Water Rating.
- Maximise sustainability outcomes for the funding available.
- Implement sustainability initiatives that are cost effective for the life of the buildings, with consideration to performance, maintenance, durability and fit for purpose.
  Provide visual demonstration at key sustainability initiatives, incorporated within the project for staff and visitor education and community engagement.

CONCLUSION

This project highlights specific design approaches developed to achieve a practical and innovative solution for a unique climate in the tropics. From understanding both the precise design objectives and the client‟s needs, the Architect is able to create the most effective solution. This solution may not necessarily be the most obvious, yet it is more pioneering and therefore creates a longstanding, lasting impression with the client and their stakeholders.

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HOUSEHOLD ENERGY DEMAND PREDICTION IN DEVELOPING COUNTRIES

Fatma Kassim Mohamed, Tomonari Yashiro
The University of Tokyo/Institute of Industrial Science, Japan

ABSTRACT

Studies show that energy demand in developing countries is expected to contribute a significant amount to the total energy demand in the near future. Although still currently small compared to demand in industrial countries, a prolonged energy demand surge poses a great threat to the environment and social development when not met adequately. Efficient energy planning and management through national and regional policies is the key in minimizing the impact of energy demand to the environment while providing a platform for optimal energy supply to meet social needs for development. Unfortunately, lack of record keeping, poor data management and detailed data availability pose a great threat in effective energy management and planning in these countries. Currently, energy policies in most developing countries are generic national policies concentrating on energy supply. There are yet no policies for the control of energy demand drivers due mainly to the lack of data.This paper introduces a new method to illicit household end-use information needed in energy consumption trend analysis and demand estimation by combining urban land use characteristics, satellite image analysis and a basic household energy survey. The methodology can then be used as a tool for energy planners and managers to establish policies on the household and regional level

INTRODUCTION

Energy demand in developing countries

Rapid population growth and urbanization in developing countries is the main cause of the rapid surge in energy demand. It is expected that out of the total energy demand in the world in the next 20 years, about 60 percent will be from these countries [IEA, 2010]. As a result to urbanization improvement to the standard of living in developing countries is also an important factor to the energy demand increase. Currently developing countries are facing a crisis on how to satisfy their energy demand. Abrupt changes in energy demand between urban and rural areas are part of the problem but unplanned energy supply and management systems contribute to the problem to a larger part.

There have been a massive number of studies showing the correlation between energy use and economic development [A. E. Akinlo, 2008; Perry Sadorsky, 2010]. Some researchers have even named energy as a prerequisite condition for economic growth and development [O.J. Ebohon, 1996]. Theoretically, energy has been shown to be equally important as other factors of production such as land, labor and capital because of its correlation with economic growth [J. Ikeme and O.J. Ebohon, 2005]. This relationship is found to be much stronger for electric energy than energy as a whole [Andrews-Speed P. and Dow S., 2000]. Since energy boots development and development boots energy demand – up to a certain point, developing countries are in a constant battle to maintain energy balance to support development and social advancements. Currently, however, the energy status in developing countries is very unstable with frequent power shortages and unsatisfactory services in other sources of energy such as petroleum products and semi-formalized traditional energy such as charcoal. Even traditional energy sources such as firewood are under strained conditions due to long dry spells, environmental degradation and deforestation.

Urbanization

Energy use in developing countries is still concentrated in urban populations [Stephen Karekezi and Lugard Majoro, 2002]. The urban population in Sub-Saharan Africa alone increased from 22 percent to 36 percent between 1980 and 2005 [The World Bank, 2011]. While the population in developed countries is seen to be larger in the urban centers already, developing countries are expected to experience large rural-urban shift in the near future. Sharp increase in the population in urban areas in the less developed areas is in sharp contrast to the population decline in the rural area. The rate of urbanization in developing countries is expected to remain high until from the year 2030 where it is expected to undergo a much slower growth. The urbanization rate in Sub-Saharan Africa is at an average of 5 percent followed by the East Asia and Pacific region [The World Bank, 2012]. While most developed countries reaches saturation points before year 2025, urbanization trend potential in developing countries seems to continue beyond year 2050. The United Nations projects that by 2030, 60 percent of the total world population will be in the cities [UN, 2011].

The International Energy Agency predicted that about two thirds of all energy consumed in the world is in cities around the world even though only around one half of the population lives in urban areas. By

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2030, increase in urbanization will drive up city energy to 73 percent of the worlds' energy use where 80 percent of this increase is expected to be in developing countries [IEA, 2010] . It is understood that due to better availability of energy services in the urban areas coupled with improvement in the standard of living, modern energy intensity per urban capita is higher than the national average. In China for an instance, the energy intensity per urban capita is 1.82 times the national average [IEA, 2010] whilst in Tanzania in 1993, the urban modern energy intensity was about 4.4 times the national average [R. Hosier,1993]. Hosier concluded that one rural person migration to the city results in a tripling of the economic costs for supplying that person's energy needs [R. Hosier, 1993]. In Tanzania, while the rate of electrification for the whole country is around 15 percent, only 2 percent is in the rural area whilst 39 percent is in the urban area. Out of all the energy consumed in Tanzania 50 percent is consumed in the largest commercial city, Dar es Salaam [Alex Kyaruzi et. al, 2012; Helio International, 2006]. Hence, understanding the energy use in the urban center in developing countries is important in understanding the total energy use trend.

Household sector

The household sector in developing countries makes up a large share of the total energy consumption. In Tanzania, 72.5 percent of the total energy consumption is in the residential sector, whilst being 80.63 percent in Kenya and 81.01 percent in Nigeria. Out of which, traditional biomass fuel is 97.2 percent in Tanzania, 94.7 percent and 98.2 percent in Kenya and Nigeria respectively [IEA, 2009]. Even though the most commonly used fuel in residential sector in developing countries is traditional biomass, residential sector has a strong impact to the modern fuel use especially in countries without a strong industrial sector. Twenty seven percent of the total electricity use in Kenya is in residential sector, 56.3 percent is used in Nigeria and 45.5 percent in Tanzania [IEA, 2009].

The energy demand pattern of the poor households largely evolve around household energy end-use of cooking and lighting while the wealthier households have more end-uses such as refrigeration, air cooling, information and entertainment, and domestic water heating. The effect of residential energy consumption is not only felt in the total national energy consumption but also in the daily peak demand. Energy required to meet residential end-use demand affects the amount of energy needed to be produced at the national level to meet that demand. The demand in residential area is locality specific and can have a higher intensity in one locality compared to another. Appliance ownership rate, which plays an important role in modern energy demand, especially electricity is also influenced by urbanization [Michael A. McNeil]. McNeil concluded that the rate of refrigerators ownership is not only affected by household income but also urbanization whereby households in areas with high rate of urbanization own more refrigerators than households with the same income level in less urbanized areas. This means that by understanding the energy demand drivers in developing countries' household sector in the urban centers can help in controlling to a large extent the energy demand in these countries

Data availability

While conducting a survey on the energy use pattern in slum dwellers in Nairobi – Kenya, Stephen Karekezi, et al. [2008] mentioned limited availability of secondary data and information sources for crosschecking the primary data for consistency and accuracy as a limitation for their survey. This limitation is consistent throughout energy studies in developing countries. For instance, models found in literatures mainly use national level data to simulate energy demand in developing countries even when simulating energy consumption trend in the household level. This is mainly caused by lack of grass root level data. Biswas [1990] states that data concerning energy infrastructure in developing countries is very limited. Moreover, poor or non-existent data management, inter-ministerial or inter-institutional rivalry, unnecessary classification of data as secret or confidential combined with official apathy often result in unavailability of the data that actually are collected. Moreover, when data is available, its reliability is not guaranteed.

The International Energy Agency [IEA, 2005] established a set of indicators to assess country's energy efficiency performance and benchmarking. When reviewed by The World Bank [Dian Phylipsen, 2010] for their application to formulate and evaluate progress of Energy Efficiency policies in developing countries, it was found that end-uses and activity data was lacking hence limiting indicators when available to the national and sectoral level. This limits the extent to which the indicators can be used for energy efficiency planning and monitoring. It was also noted that lower aggregation level data requires specific surveys and analysis and is not found on regular statistics. End-use data gathering procedure development and strengthening was proposed for efficient indicators use in policymaking and identification of available activity data and surveys for additional data collection was also recommended. It was also found that there is no clear understanding between efficiency indicators and policy implications in some developing countries. While compiling the energy access situation in developing countries, UNDP and World Health Organization [2009] stated that while data was sought it was not always found

for all developing countries and estimations had to be made. Where data was available for two out of three – national, urban, rural levels – estimates were made for the third using the available information. Where data from some countries were missing, estimates of global and regional access for developing countries were produced using a simple extrapolation process where the extrapolation involved aggregating the data from countries were that particular data is available and assuming that the level of access is the same in the countries without that data.

Under the background of constrained data availability in developing countries, energy demand estimation model is proposed in this study to be used as a tool for energy planners and managers in controlling future energy demand.

METHODOLOGY

From the literature review and direct interviews with energy managers and policy makers, it was found that developing countries are facing a huge problem in energy management and appropriate policy mechanism due to a lack of detailed data on energy consumption. As a result, energy policies in these countries concentrate on the national or sectoral energy demand management and ignore locality based management and end-use planning. In developing countries where the household sector contributes a high percentage of the total energy demand, understanding the drivers in the household sector is important in making informative decisions on energy management and policy making. To overcome the lack of energy data limitation, a new methodology to estimate energy demand in developing countries is proposed.

Hypothesis

Firstly, a new method to collect regional/locality level data was introduced. The basic hypothesis behind this method is the assumption that households form or are segregated in zones of similar income and consequently similar energy consumption intensity since energy use is directly related to income.

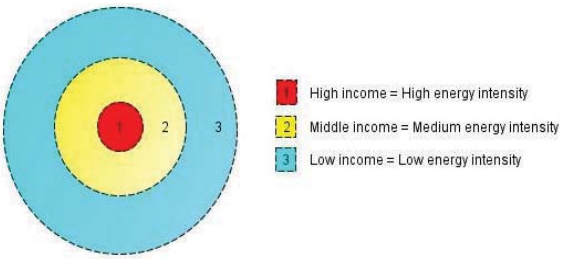


Figure 1: Hypothesis – Income Vs Energy

Using this hypothesis, total energy consumption intensity in each zone is aggregated to calculate the total energy consumption intensity of the whole area.

Since the hypothesis requires the establishment of energy consumption intensity zones, land use analysis involving regional planning and master plan analysis is proposed. From the land use analysis, zones having similar household income and consequently similar household energy demand are established. Housing density, housing type and social services availability are taken as indicators when analyzing the income distribution in an area. Low housing density in well planned neighbourhood with complete set of social services such as electricity, clean water, sanitory systems and security is taken as an indication of high income area. Satellite pictures taken from samples within these zones are analyzed and the total number of houses in each zone is computed.

From then onwards, a simple household energy use survey from a sample in each established zone is conducted in order to understand the appliances penetration level in each income zone, the number of hours they are used per day, and the quantity of appliances per household in each income zone. The survey also looks into the appliances energy consumption (power ratings) to understand the difference – if any – of appliances' efficiency in each income zone. This information together with the data collected by land-use analysis is then inputted in an end-use model to predict the future energy demand of that locality.

Model simulation

To analyze and test the model, Dar es Salaam city in Tanzania was chosen as a case study. This city is chosen because it is among the top ten rapidly expanding cities in the world and experiences acute energy shortages – especially electricity. Three master plans of 1954, 1969 and 1979 were analyzed together with current infrastructure and land use reports to establish the household zones per income. The housing density, housing type and avalibility of social services such as garbage collectors, clean water and electricity in a neighborhood indicated that the northern area of the central business district along the Indian Ocean coast is a prime housing area with plot values decreasing further from the coast. Satellite image analysis confirmed that the housing density is the lowest from the coastal area inwards establishing the zones for middle/high income households along the coastal area to the north and low-income households in the unplanned settlement areas in the hinterland [Figure 5].

Household energy use survey was then conducted via three different media; Word file though emails that

got 48 responses, paper handouts that got 52 responses, and an online version that got 57 responses; 157 in total. The survey asks on the energy use for cooking and lighting together with the type of electrical appliances the household own. It also asks on the number of hours the appliances are in use together with their quantity. Another survey was conducted on site on 53 households to understand appliances power and efficiency. This information is inputted in an end-use model proposed to simulate the energy demand for Dar es Salaam for the year 2012.

The end-use model combines the aggregated energy in each household by calculating the total energy use by each appliance use as follows:

$$\text{Energy consumed by End Use}_i \text{ in House}_i \left(\frac{KWH}{Year}\right) = \text{Appliance Power } (W) \times \sum^{n} \text{Appliance} \times \sum^{24\,hours} \text{Time of Use} \times \sum^{366\,Days} \text{Days of Use}$$

$$\text{Energy consumed by all End Uses for Group}_i \left(\frac{KWH}{Year}\right) = \text{Electrification level} \times \sum^{n} (\text{End Use}_i \times \text{Appliance}_i \text{ Penetration level}) \times \sum^{N} \text{Houses}$$

When the results are compared with real consumption energy [Source: Tanzania Electricity Supply Company - TANESCO] they show a close similarity at 0.4 percent difference. To validate the model, Malaysia's appliances use characteristics [Malaysia Bureau of Statisctics, 1999] was used because of the geographical, climatic and cultural similarities between Malaysia and Dar es Salaam, Tanzania. The simulated results using Malaysia's information differs to when Dar es Salaam's information is used by 3.01 percent for year 2012 consumption.

The results indicate that the model hypothesis is sound and the energy use characteristics between the two income groups can be used in energy demand estimations forecasting in developing countries that lack detailed energy use data. Drivers behind the energy demand in the forecasted years can then be understood and appropriate actions can be then taken by energy planners for energy sources optimization.

Model application

The model was then used to forecast energy use for Dar es Salaam region for the year 2020 and year 2030. Under the forecasting conditions, household income group (middle/ high income households) was taken to expand with time and so does appliances penetration level. The rest of the parameters are taken to be at a fixed value rached in year 2012 illicited in the household energy use survey conducted for this study.

To observe the change in appliances penetration level and middle/high income group growth trend, historical data from national budget survey conducted in the national census is used. Information for the year 2001 and year 2007 are available for the case of Dar es Salaam and this data is coupled with the year 2012 data collected in this study to understand the energy demand estimates. The growth trend of the two factors – middle/high income household group expansion and appliances ownership level expansion – is taken to be under a polynomial function with an order k and constant C_i is used

$$y = c_0 + c_1 x + c_2 x^2 + \cdots + c_k x^k$$

Two functions for the appliances ownership growth were derived using historical data from the national budget survey - giving slow appliances ownership growth, and the historical data combined with data from the survey conducted in year 2012 – giving high appliances growth rate. The demand estimates for the two years are plotted together with the real consumption data for the years 2007 to 2012 given by Tanzania Electricity Supply Company – TANESCO. It should be noted that up to the year 2012, only 43 percent of the total households in Dar es Salaam were taken to have electricity whilst all households in the city were taken to have electricity in the estimated years of 2020 and 2030.

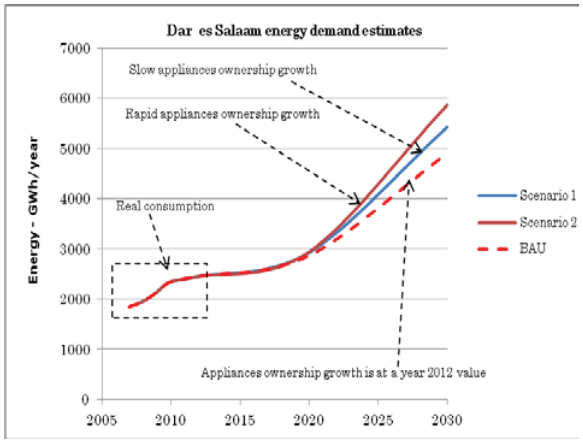


Figure 2: Hypothesis – Income Vs Energy

In the period of ten years between year 2020 and 2030, the total unconstrained demand is seen to increase by about 185 percent. The load share of appliances for the year 2020 and 2030 under slow appliances penetration level growth (Scenario 1) show a huge shift between the year 2020 to year 2030

where the biggest load share change is in lights – from 33 percent to 27 percent, followed by air conditioners – from 37 percent to 42 percent. The load share of washing machines changes from 3 percent to 5 percent from year 2020 to year 2030. The load share of refrigerators show a decrease from 10 percent to 8 percent within that change of time. The results show that lights being the most common appliance has the highest impact to the energy use but the effect of the expansion of the middle/high income household group favouring high ownership rates of comfort appliances such as air conditioners, washing machines and water heaters will have a greater impact with time to the total energy demand in the city of Dar es Salaam and consequently Tanzania as a whole.

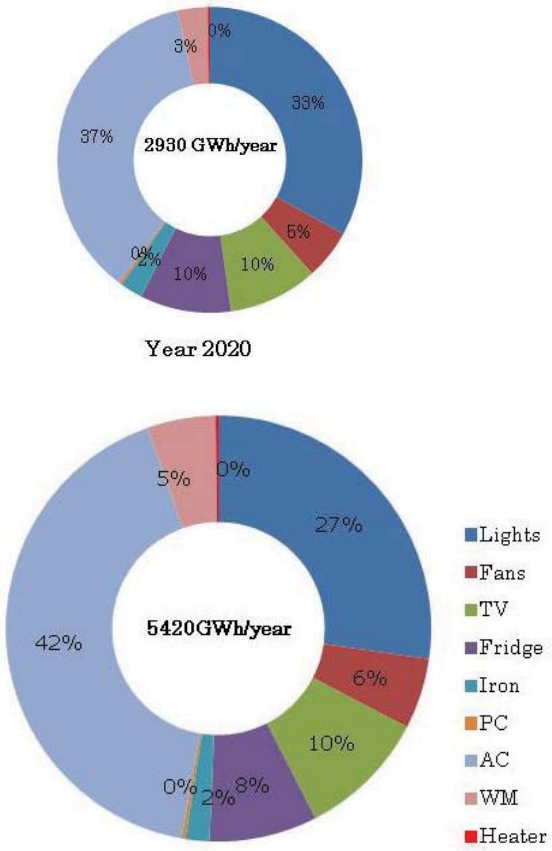


Figure3 : Appliances load share

CONCLUSION AND DISCUSSION

Although the method introduced in this paper is established under a very limited data availability condition, the results reached can be used to give basic explanations of expected energy demand growth in developing countries.

Using the methodology proposed in this study, the energy demand drivers in the household sector in developing countries lacking detailed energy consumption data can be understood. Policy makers can then use this methodology as a tool to plan and control demand for optimal resources utilization. For instance, by controlling the load share of energy used by lights in Tanzania in the low income households by the introduction of efficient light bulbs from the current 60W bulbs to 30W bulbs, a 25 percent change to the more efficient 30W bulbs in the low-income households alone can conserve about 108GWh/year while a hundred percent conversion can conserve 430GWh/year. Controlling the efficiency of air conditioners imported in the country through labelling and other incentives can also contribute greatly to the energy management in the country since the effect of the appliance is seen to be growing with the improvement to the standards of living.

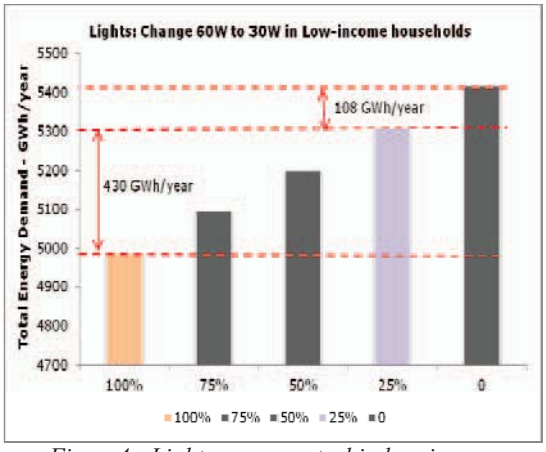


Figure4 : Light power control in low-income households

Thus, this method can be used by energy planners to make informed decisions on energy policies in developing countries that focus on a smaller locality level compared to the current national level and on the end-use level compared to the current sectoral level.

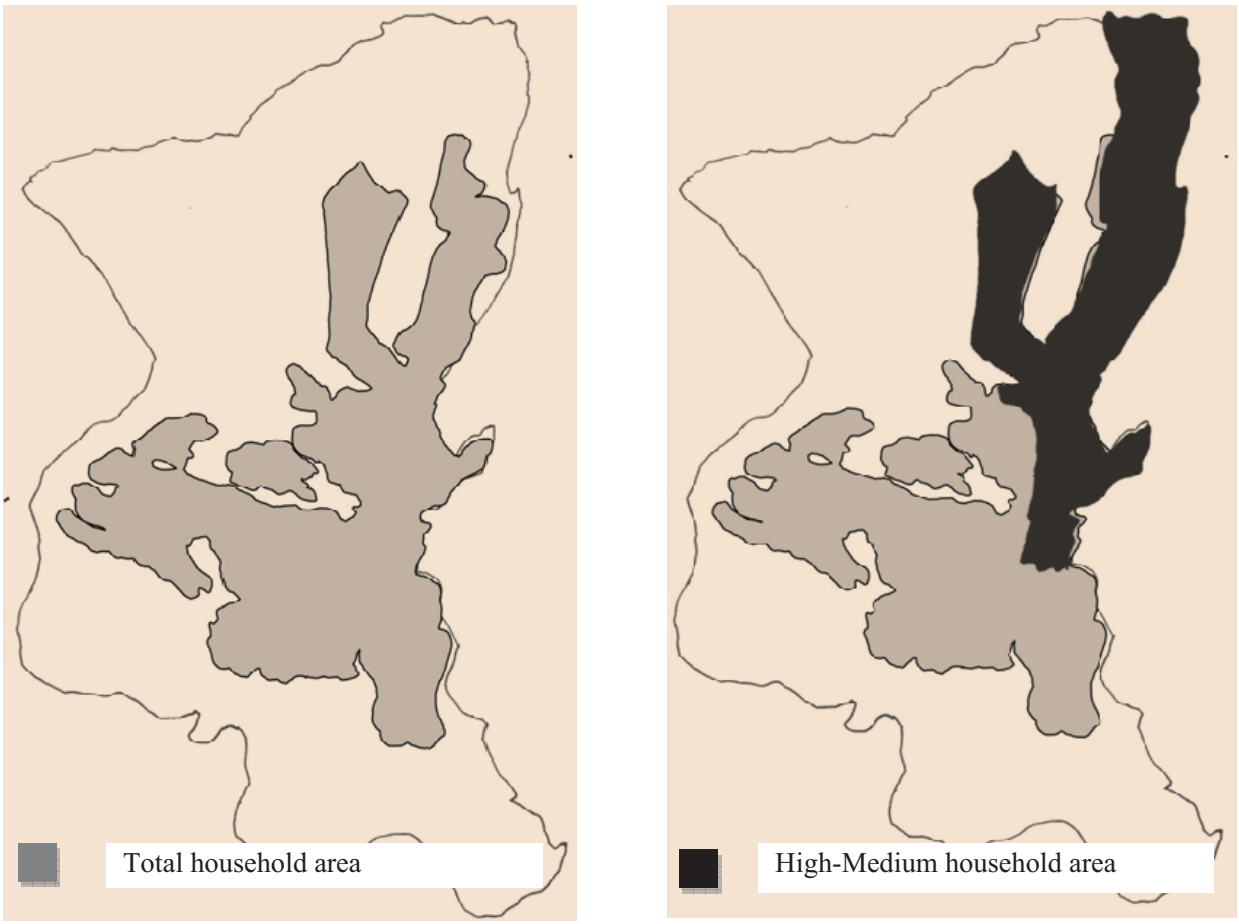
Although this method can be used as an important step in a more detailed energy management in developing countries, energy use data recording is recommended in these countries for more precise results and consequently better and more poignant policies.

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Figure 5: Dar es Salaam Housing income zoning



DRIVING INNOVATIONS TO DEVELOP PUNGGOL TOWN AS THE ECO-TOWN OF THE TROPICS

ER. DR. Johnny Wong Liang Heng, Housing and Development Board, Singapore

ABSTRACT

The Housing & Development Board (HDB) has positioned Punggol Town, planned at the onset towards achieving sustainability, as Singapore's first Eco-town of the tropics. This follows its first eco-friendly public housing development, Treelodge@Punggol, through passive design strategies and active technology adoption in the areas of greenery enhancement, energy efficiency, and water and waste management. The results obtained quantitatively demonstrated the benefits of the various eco-features introduced towards achieving environmentally sustainable public housing. This allows HDB to replicate the tested initiatives on a larger scale in its bid to drive innovations to develop Punggol as the Eco-town for the Tropics. The possibilities for future development of new sustainable technologies are endless and HDB's Punggol Eco-town is just the beginning.

INTRODUCTION

Overview

The Housing and Development Board (HDB) is the largest developer in Singapore, seeking to create well-designed, sustainable and community-centric towns towards achieving better HDB living for over 80% of Singapore's population. Specifically, HDB plays a major role in promoting environmental sustainability with the industry, through practical R&D involving the identification, testing and implementation of practical and cost-effective green building technologies, sensible urban design strategies and innovations in its public housing developments.

Punggol Eco-Town

Planned to promote sustainable living from the onset, Punggol has a wide range of quality housing with supporting facilities and a well-integrated public transport network that serves the needs of the town. Located in northeastern Singapore and as the youngest HDB town, Punggol presents a good opportunity to demonstrate sustainable urban planning and design, green technology adoption and active community partnership. As such, HDB is developing Punggol Town into Singapore's first Eco-Town - 'The Sustainable Waterfront Town in the Tropics'.

An eco-town with its own character, Punggol sets itself apart from other eco-cities, seeking to develop urban solutions that address high rise high density cities particularly in the tropics and sub-tropics that are reasonably simple and affordable. In this way, the solutions would be more replicable and scalable to many Asian cities.

Treelodge@Punggol: HDB's First Eco-Precinct

Treelodge@Punggol, as HDB's first eco-friendly public housing project and having been accorded the Green Mark Platinum Award, sets a new benchmark for future public housing to encourage the community to lead an eco-lifestyle. Comprising seven public housing blocks with 712 residential units, a podium carpark and generous provision of green spaces throughout the 2.9-hectare development, it serves as a 'Live-in Laboratory' where HDB has brought together sustainable urban design with green building technologies in a single demonstration project. The guiding design principle seeks to harness the elements of nature, such as wind, daylight, rainfall and greenery in order to promote sustainable green living, whilst actively adopting green building technologies. The integrated laboratory allows HDB to measure the collective effects of the design and technologies towards achieving environmental sustainability, before scaling and replicating these successful urban solutions to the rest of Punggol Town.

This paper will focus on several key research areas in Treelodge@Punggol and the results obtained from studies in these areas, before explaining the efforts made to replicate the innovations on a larger scale.

RESEARCH AREAS

The features incorporated in the precinct fall within the following key research areas:

a) Enhanced greenery
b) Energy Efficiency
c) Water & waste management

Enhanced Greenery

The provision of greenery in urbanized settings is recognized for the generation of numerous environmental, ecological and socio-economical benefits, such as relieving the Urban Heat Island Effect. Greenery also enhances the aesthetics within precincts, thus creating a conducive living environment, especially in densely built-up areas.

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The greenery provision of Treelodge@Punggol was greatly enhanced. A Green Plot Ratio[1] of 4.14 was achieved, compared to typical new HDB developments, which achieve Green Plot Ratios of 3 to 3.5. The generous provision was introduced to

a) reduce the Urban Heat Island Effect,
b) reduce ambient temperature in the precinct,
c) reduce reflected glare from lower levels,
d) reduce noise levels in estates and
e) enhance overall aesthetics of the development

The high provision was the result of several concepts and innovations.

Firstly, Treelodge@Punggol adopted the landscape eco-deck concept where the blocks sit on a podium level car-park, maximizing the opportunity for green and social spaces at the landscaped eco-deck.

Secondly, the adoption of a hybrid green roof system makes extensive greening on the eco-deck possible. This system reduced the depth of the soil bases required for planting and the size of the deck structure. Large trees were grown at the carpark level and were allowed to emerge through air-wells to complement the hybrid green roof system.

Thirdly, green roofs were introduced on the roof decks of the seven residential blocks. This was done to further enhance the thermal comfort of residents living in the topmost storey. HDB's patented Prefabricated Extensive Green (PEG) Roof system was used to achieve this at a low maintenance cost.

Microclimatic Study

In order to validate the hypothesized environmental improvements of enhanced greenery, a microclimatic study was conducted. This took place in two phases before and after greening of the Eco-deck.

During the study, the ambient air temperatures at multiple locations on the Eco-deck of Treelodge@Punggol were measured using temperature dataloggers in order to investigate the effectiveness of greenery in reducing ambient air temperatures.

The temperature results were compared for the time range of 12pm-2pm, when the typical daily maximum temperature occurs in Singapore. The temperature range was observed to fall from 32.8-34.6°C to 31.8-33.9°C following the addition of greenery. These figures are reflected in Figure 1. The significant reduction of ambient air temperatures by an average of 0.9ºC was a validation of the hypothesis that greenery provision would lead to ambient temperature reduction.

The reduced ambient temperature will help to make community spaces more conducive for residents' enjoyment, while reducing residents' need to use mechanical means like air-conditioning to achieve thermal comfort.

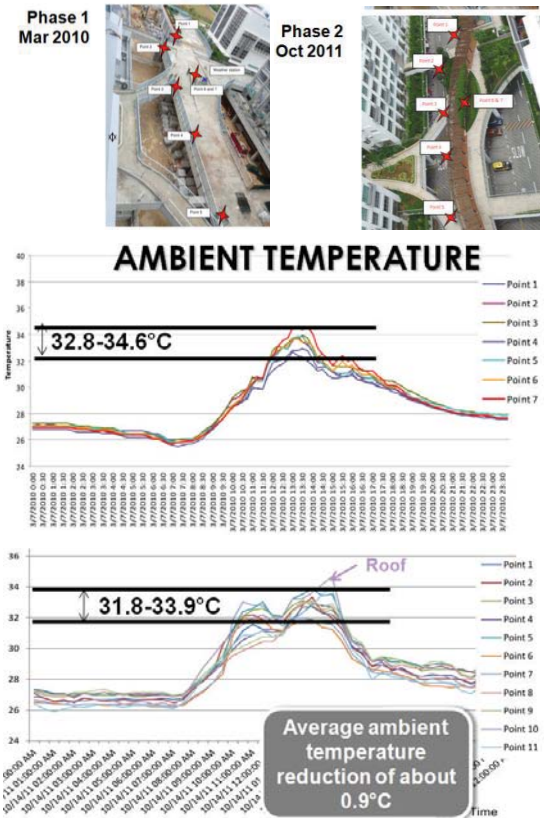


Figure 1: Microclimatic Study Ambient Temperature Results

Energy Efficiency

Household energy consumption forms about 9% of the total energy usage in Singapore. Planning and designing energy-efficient buildings will help reduce global and local environmental impact, through reduced utilization of non-renewable resources and related environmental impacts, such as air pollution.

Energy efficiency was emphasized in Treelodge@Punggol through optimizing passive design strategies and adopting active design strategies.

Passive Design Strategies

During the planning phase, the prevailing north-east wind for the precinct was taken into consideration. All residential blocks were strategically placed with façade windows that face the prevailing wind to maximize natural lighting and ventilation. This also

[1] Green Plot Ratio quantifies the amount of plant volume in a development site (measured in terms of total leaf area).

helps to minimize solar radiation from the sun into the units and reduces the energy consumption caused by the use of air-conditioning.

Validation Study on Wind Flow Analysis

Based on the predominant wind direction in Punggol town (North and North-east direction), a detailed wind flow analysis was carried out through Computational Fluid Dynamics (CFD) modeling at precinct, block and unit level during the design stage of Treelodge@Punggol. Through analysis of the wind profile, the design was fine-tuned to prevent 'stagnant' areas with low air flow, thus enhancing the natural cross-ventilation across the precinct. For example, triple volume voids were created in some of the residential blocks to allow better cross ventilation into the eco-deck.

Real time data was collected using monitoring devices during and after the construction stage. The CFD analysis was then validated using the actual wind profile observed at the site after its completion.

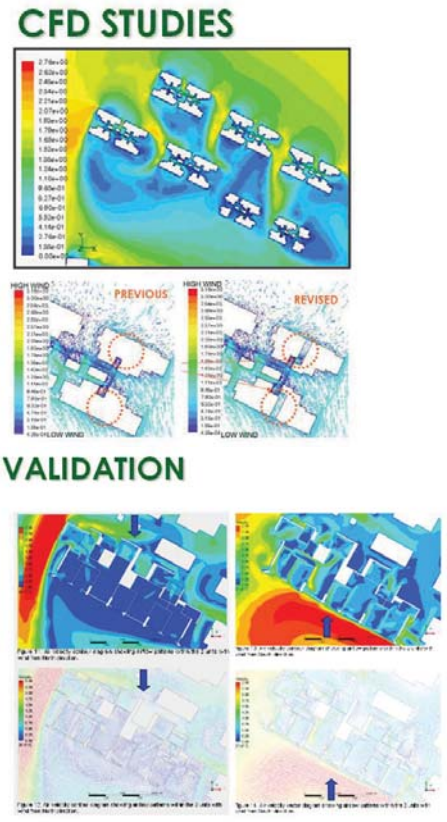


Figure 2: Validation of the wind flow analysis

In the comparative study (see Figure 2), an average wind velocity of 0.4-0.6m/s was recorded on site. This was similar to the result generated from the CFD studies. This demonstrates that advancements in computational modelling had made it possible to simulate microclimatic conditions accurately. This would enable HDB to determine the cross-ventilation performance across Punggol and the effects of urban design at both macro and micro levels.

Active Design Strategies

Energy is required to power lighting in the precinct at night, the lifts to provide vertical transportation and the pumps to supply water to the water tanks. Apart from using passive design to reduce energy consumption, active design strategies help to optimise the energy usage and reduce maintenance costs.

Energy-saving light fittings such as LED light fittings were installed in common corridors and in the podium carpark as they have a longer lifespan and greatly reduce energy demand. In addition, motion sensors were placed strategically at staircase half-landings and in the carpark to provide on-demand lighting, further reducing energy consumption. The lifts in Treelodge@Punggol include an energy regenerative system to recover kinetic and braking energy that would otherwise be lost as heat.

Solar photovoltaic (PV) panels with a total capacity of 280kWp were installed at the rooftops to harness solar energy to power the aforementioned common services such as common area lightings, lifts and pumps.

Energy saving study

After the completion of Treelodge@Punggol, a Building Monitoring System (BMS) was installed to monitor the solar energy generation and common area energy consumption.

The Solar PV system generated an average of 3700 kWh of solar power per block per month (see Fig 3), which is sufficient to meet approximately 90% of the of the total common services energy requirement.

With the implementation of energy-efficient lighting and energy-efficient lifts, the average energy usage for the common services was 38.4 kWh / dwelling unit / month, about 32% lower compared to other new HDB developments in Punggol (see Fig 4).

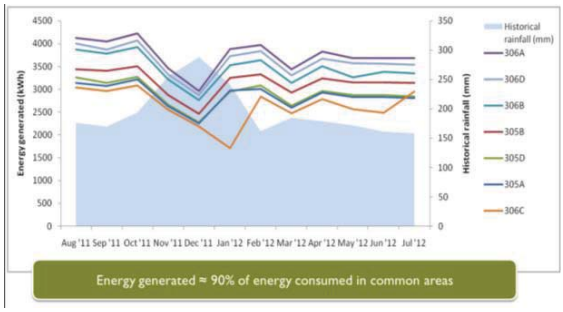
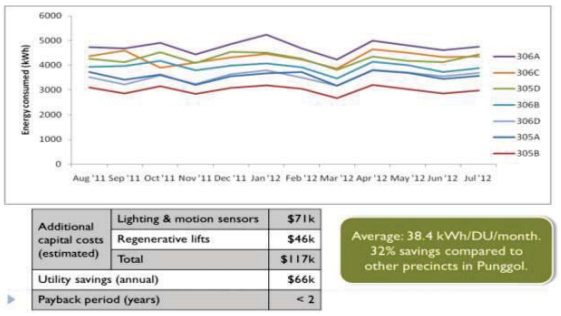


Figure 3: Solar Energy Generation



Additional capital costs (estimated)	Lighting & motion sensors	$71k
	Regenerative lifts	$46k
	Total	$117k
Utility savings (annual)		$66k
Payback period (years)		< 2

Average: 38.4 kWh/DU/month. 32% savings compared to other precincts in Punggol.

Figure 4: Common Area Energy Consumption

Waste and Water Management

Water Conservation

Efficient water management was an important factor in designing Treelodge@Punggol. The precinct incorporated a rainwater harvesting system with storage tanks at the top-most storey of each residential block. The harvested rainwater was treated with a chemical-free treatment system to remove up to 80% of bacteria, allowing the water to be used for non-potable purposes, such as common area washing and irrigation. This lowered the usage of potable water in common areas. The use of gravity to distribute the treated rainwater to lower floors reduced the energy required for water distribution further. Detailed studies are currently being conducted to determine the effectiveness of the rainwater harvesting.

To help residents conserve water within the residential units, water-efficient fittings which meet the PUB Water Efficient Labeling Scheme devices (2-ticks) were provided. All bathrooms were also fitted with an innovative integrated wash basin-toilet eco-pedestal system that allowed residents to save about 10% of the water used for flushing the toilets. The eco-pedestal enabled water used for hand-washing to be re-directed to the pedestal cistern for the next toilet flush. Further water conservation was achieved through the inclusion of a dual flush feature, allowing the user to vary the amount of water used for flushing.

Surveys were conducted with the residents to seek feedback on the eco-pedestal. It was found that residents generally supported the initiative as they found it useful to help them conserve water. Residents' feedback on the design of the eco-pedestal also helped in refining the eco-pedestal for wide-scale implementation, including improving the flow rate for hand washing, enlarging the basin and providing more space for a soap dish (see Fig 5).



Figure 5: Eco-pedestal improvements

Waste recycling

To promote waste recycling, a Centralised Chute for Recyclables system was introduced to all the blocks, in addition to the original centralised refuse chute. Dedicated for recyclable waste, the system provided added convenience for residents to recycle, whilst improving the waste collection efficiency.

Study on Recyclables Collected

Recyclable waste collection was monitored over a one-year period. With the introduction of the Centralised Chute for Recyclables system, there was a significant increase in recyclables collected. The recyclable waste tonnage was observed to be more than four times the amount collected compared to a typical HDB block with a recycling bin at the ground floor (See Fig 6). The study also provided quantitative results that would be useful in waste logistics planning. It was observed that over the festive season in December and February, there was a marked increase in the amount of recyclables collected.

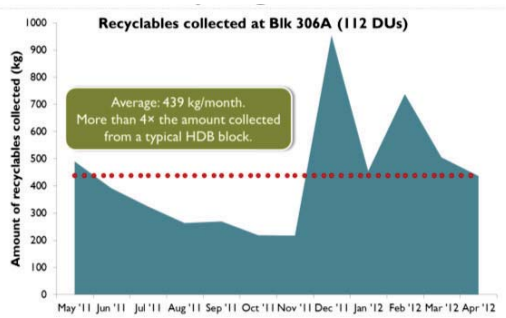


Figure 6: Amount of Recyclables collected

Community Effort

Beyond sustainable design and green building technologies, active resident participation is important in creating a green living lifestyle. A series of programmes and initiatives was developed to educate, engage and enable the community to embrace an eco-friendly lifestyle. The provision of cost-effective and space-efficient dual bicycle parking facilities and the introduction of a car-sharing scheme helped encourage adoption of green commute

modes, whilst a community garden at the centre of the eco-precinct enables greater community participation and interaction through green activities.

Post completion Survey on Eco-Friendly Practices
A survey was conducted in 2011 to determine the receptiveness towards a green living lifestyle amongst Treelodge residents. The surveys were conducted via face-to-face interviews amongst a total of 256 randomly selected residents from Treelodge@Punggol. Over 90% of respondents expressed their support for the various eco-features that were introduced both within their homes and in the precinct (see Figs 7 and 8).

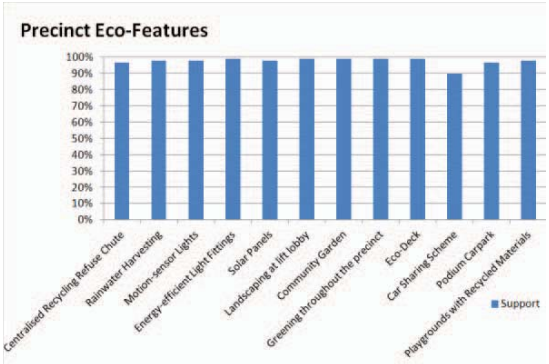


Figure 7: Survey Findings for Precinct Eco-Features

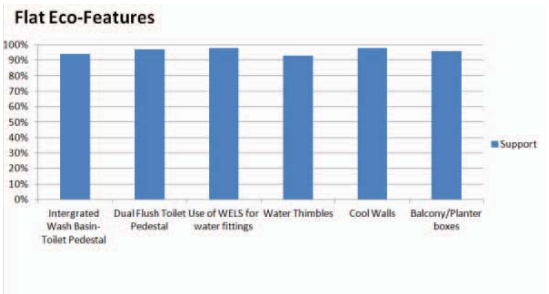


Figure 8: Survey Findings for Flat Eco-Features

Replicability & Scalability in Punggol Eco-Town
With promising results derived from the study on Treelodge@Punggol validating the measures introduced, workable eco-features were implemented to new public housing developments under construction or launched after Sep 2011. Some of these eco-features include lush greenery to reduce the urban heat build up, centralised refuse chutes for recyclables to promote recycling, rainwater harvesting systems to encourage water conservation, energy re-generative lifts, LED fittings with motion sensors, fuel cells to enhance energy efficiency, and computational fluid dynamics analysis to capitalize on wind to cool the environment.

For existing developments, HDB is working with Pasir Ris-Punggol Town Council to introduce energy urban solutions to 180 existing blocks in Punggol by 2015. The solutions include LED lighting and re-generative lifts to help improve energy efficiency in existing estates. HDB has also developed a new business model to tap on private enterprises in the wide-scale implementation of green technologies. Singapore's first solar leasing project comprising 2 mega-watt-peak (MWp) systems was completed in 2012 with solar energy generated to power the common services (common area lighting, water pumps and lift services) for 40 residential blocks. Another tender to install 3MWp for 80 blocks is currently underway and is expected to be completed in end 2013.

A holistic and comprehensive framework that covers social, economic and environmental considerations was developed to steer the development of Punggol Eco-Town. The framework sets out 10 key desired sustainability outcomes with broad strategies and initiatives to achieve them. The environmental strategies focus on reducing carbon emissions, encouraging greener forms of transport, enhancing greenery and biodiversity, achieving effective water and waste management and providing a clean, healthy and comfortable living environment. To ensure social sustainability whilst meeting the evolving and diverse social needs of a wide spectrum of residents, the social strategies seek to encourage more social activities and instil a greater sense of ownership and identity. The strategies for economic sustainability focus on creating economic and social vibrancy within Punggol Town Centre.

HDB has also expanded the CFD analysis beyond precincts, with town-level environmental modelling to simulate microclimatic conditions (wind flow, temperature, and solar irradiance). This allows HDB to study the impacts on Punggol's urban design at both macro and micro levels. The results are used to optimise the building designs to reinforce HDB's passive design strategies. At the precinct-level, air flow between residential blocks can be examined using CFD analysis, and building design and spacings can be refined to prevent air stagnation. At the town-level, air flow across precincts can be examined to ensure that precinct designs do not impede air flow between neighbouring precincts, thus achieving effective cross ventilation across the entire town. HDB has also worked with NUS academia on a Township Climatic Mapping study for the entire town to examine the macro scale effects of ambient temperature, wind, solar irradiance and shadow effects, etc to aid in the town planning and development for Punggol Eco-Town.

HDB is also developing an Urban Systems Model, which can be used to guide planning and design decisions. The model comprises 6 inter-connected environmental sectors and provides an analysis of the energy and carbon emissions generated by the town, depending on the trade-offs between urban form,

infrastructure and technology alternatives. The model allows refinements to land-use and urban design plans for the town to be made based on model predictions on the performance of the various initiatives set out for Punggol.

Beyond technology, community efforts to embrace an eco-friendly lifestyle have also been embarked on in Punggol. There are ongoing plans to develop an extensive cycling network for Punggol Eco Town to promote green commutes. These include the implementation of cycling paths in new and existing developments that take the safety of the cyclists into consideration to encourage non-motorised transport.

CONCLUSION

Punggol Eco-Town presents an opportunity for HDB to redefine our urban landscape to make the town more sustainable and liveable. Following the successful validation of the eco-features introduced in Treelodge@Punggol, many of the proven green building technologies have been incorporated into new developments within Punggol Eco-Town, whilst existing developments have also been retrofitted with selected solutions to make them sustainable in the long run.

With a holistic framework to guide the development, HDB has taken steps towards fulfilling the various desired outcomes, which has gained pace with new urban design plans and new developments brought about by HDB's ramped-up building programme. In addition, Punggol Eco-Town serves as an excellent platform to test out new ideas, innovations and technologies with various stakeholders and to identify workable ones that can be replicated in other towns. The scale of implementation also allows HDB to achieve cost efficiency with economies of scale.

Notwithstanding the importance of cost-effectiveness, Punggol Eco-Town can be the platform for HDB to pursue qualitative benefits in relation to national issues and challenges, such as improvements in quality of life, liveability and productivity. Moving forward, HDB will identify more new eco-ideas to introduce in Punggol and develop these ideas into future eco-solutions for Punggol and future towns. The possibilities for future development of new sustainable technologies are endless and HDB's Punggol Eco-town is just the beginning.

GRAPHS OF BIOCLIMATIC REALITY TO OPTIMIZE STATIC, OPERABLE AND DYNAMIC PASSIVE STRATEGIES THROUGH THE BUILDING LIFE-CYCLE

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ABSTRACT

Fenestrations are key components of buildings passive strategies. By adding a dynamic capability such as dynamic glazing, solar protection or window treatment, these passive strategies become operable (i.e. manually controlled) or dynamic (i.e. automated). This dynamic feature raises passive strategies to the next level in terms of sustainability and savings. However, it also adds complexity what increases the risk for the passive strategy to become counterproductive. To avoid this, stakeholders must understand the bioclimatic reality of their building at different levels in order to speak efficiently with each other and come to the right decisions. Recognizing the huge spectrum of competencies required to define, design, build, commission, operate and decommission a building plus the long period of time over which a building spreads its life-cycle, we need an efficient method of communication easily and quickly assimilated by anyone having common sense.

For the last couple of years, we have developed graphs that translate the bioclimatic reality of buildings for ease of understanding. Within SOMFY, we use these graphs to define the right solar protection and the optimal control rules. We also use these graphs to support our expertise and explain the bioclimatic façades specifications to stakeholders. The paper presents the lessons learned and the usefulness of these graphs through the building life cycle.

INTRODUCTION

Passive strategies define how the building plays with its natural environment for the benefits of its occupants. They set the energy requirement level of the building while enhancing its biophilic performance. Implementing passive strategies in the buildings must always come first to be truly sustainable. (Neuman et Loftness, 2013). In bioclimatic architecture, professionals defined an optimized set of passive strategies for the building.

For millennia, passive strategies have been the only effective option for builder-architects to design comfortable home and buildings. Over time, builder-architects have improved their art, learning from their peers and their own constructions. Wherever human beings have been long enough on Earth, there is a local traditional architectural optimized the traditional local lifestyle and local climate.

In the industrial revolution, situation has changed. Several forms of energy were harnessed. They were to be plentiful, reliable and economical forever. The building industry saw the opportunity to free itself from the need to design buildings with the bioclimatic reality. During this period, new active solutions were also invented to generate and to control artificial environmental conditions for the occupants. Eventually, professionals neglected the passive strategies.

The increasing role of active solutions challenged the building industry. Professionals had to specialize, leading the loss of the generalist builder-architects. Working for the world's leading manufacturer of specialized motors and controls systems for dynamic passive strategies, we have daily contact with all kind of stakeholders from all around the world. We meet architects convinced that engineers prevent them from expressing their art while engineers are convinced that architects do not know how to design buildings. We experienced first-hand how true the specialization has led to an increasing lack of communication between the professionals and therefore a lack of whole systems thinking (GreenBuilding.com, 2006). This is a huge hurdle for a sustainable building industry.

Many approaches exist to overcome this pitfall. We consider that IPD (Integrated Project Delivery) is the most promising and BIM (Building Information Modelling) has a good potential. Still, modern buildings exist on so many layers in the three-dimensional space of sustainability that it will always be difficult for stakeholders to agree on the metric they need to assess a building performance. Moreover, if some fields in sustainability have already widely recognized assessing tools (energy consumption → Energy+ …), many other fields are still developing theirs (finance → BIM 5D; environmental footprint → LCA …). Experts from different fields will have to negotiate with each other and they all need tools for that.

As expert leaders in a commercial firm, we have to be business oriented and pragmatic while assuming our corporate social responsibility. A couple of years ago, we started a work on a canvas that can be used

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all along the building life cycle to translate the bioclimatic reality of buildings. We also wanted this canvas to be compatible with another project we have – the Living Model – so we can use it over the whole life cycle of our offers (See Figure 1). The canvas has to be comprehensible by humans and machine as it has both to support the negotiations our experts will have and to be the automation rules for the bioclimatic façade in the building automation system.

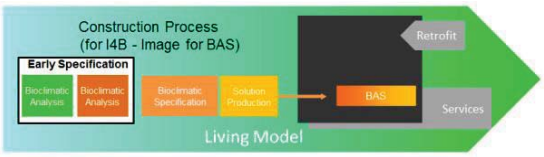


Figure 1- Life cycle to be covered by the canvas. (Living Model) (Representation based on Pfitzner et al., 2007)

RESEARCH

Framework

Stakeholders have many tools at their disposal to visualize the bioclimatic parameters of a project. These tools exposing the bioclimatic reality of a building can be sorted in two sub-families: those that point out the options the architect should explore and those that let the professionals on their own to interpret them.

Pre-Design Tools With Guidance

The Olgyay's bioclimatic chart (Olgyay et Olgyay, 1957), the Mahoney tables (United Nation, 1971) and the Givoni's bioclimatic chart (Givoni, 1976) belong to the first sub-family. There is an extended literature on them (Pedrini, 2003) (Visitsak et Haberl, 2004) (Visitsak, 2007). These pre-design tools are very informative and several of them are used by architects during their curriculum (McCartney et Matsika, 2004). Some of them are also available in software (TimeTable in Climate Consultant …). However, it appears that only experts understand them and no other professional uses them (da Costa Silva et al., 2008). We experienced it too and we concluded that this is due to the lack of interest for the occupant comfort at the earliest stage of the design. At this stage, energy with aesthetic and CAPEX are the primary concerns of the stakeholders. We have not found any tool in the first sub-family that exposes energy in an intuitive way. Even when it is visually exposed (See work of McLean and al. on the (McLean et al., 2011)). Moreover, all the tools we have found confine comfort to its thermal dimension. Therefore, they misjudge the energy requirement (i.e. bioclimatic coefficient (CSTB, 2009)) of an option for the building. Still, it does not prove there is no existing tool in the first sub-family that meets our needs. But knowing that experts need more than one simulation tools to perform a full building energy simulation (Crawley, 2005) and following the development of BIM, we conclude that there is no solution currently available and there won't be any before long. We also conclude there cannot be one unique graph from the second sub-family to expose all the points that have to be taken into consideration. The solution is not a graph per se but a canvas we exploit to expose the right way, the data at the right time and let professionals analyse them.

Pre-Design Tools Without Guidance: Canvas

The numerous existing ways to plot data exposes both the creativity of human mind and the power of infographic. To keep the graphs easy to read and printable, the canvas has to be "flat". For educational reasons we also chose to dedicate at least one dimension to time. Indeed, we experienced that professionals are focusing on space rather than time-space. Because very few data related to buildings are constant in time, professionals usually consider the extremes and mean values or they sum everything over a period of time (Cooling Degrees Days …). Even to study daylight, professionals choose specific dates and hours (Option 2 of EQc7 – LEED V4 draft for ballot). That can explain why many of them forget that a north façade in the northern hemisphere does receive direct sun from vernal equinox to autumnal equinox and it lasts from sunrise to sunset when the building is below the Tropic of Cancer. The choice to dedicate one axis to time is also motivated by our interest to promote green buildings. It is crucial from both an IEQ and an energy point of view that buildings adjust to the surrounding and indoors conditions. Modern thermal regulations are saying nothing else by being performance-based (Laustsen, 2008) and by requiring hourly or sub-hourly whole building simulation.

First solution tried

Our first attempts were with a flat 3D canvas perfectly adapted for a building automation system (BAS). This first canvas was structured with time for abscissa, a range of values for ordinate and a scale of colors as third dimension. (See Figure 2)

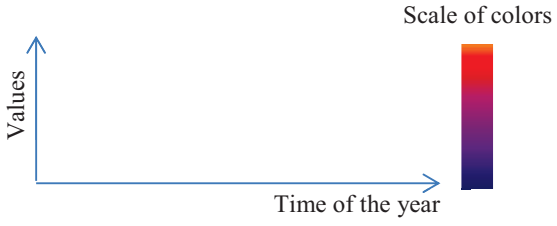


Figure 2 - First canvas tested

To generate the program for the BAS with this canvas, we mapped the existing transitions between the state of the system with the color scale and we mapped the inputs of the automated system on the vertical axis. The canvas was then transformed into an image. The BAS was reading it to know what to do at each of its time step and/or when an input data changes.

We used this canvas to expose a simple clear sky Day/Night – Direct Sun/Shadow information for an east oriented window on a cubical building located at



Figure 3 - image of one week for an east façade Location Cluses, France. (Generated with the first canvas) (Black = Night; Orange = Day + Direct Sun) (Grey = Day + Shadow)

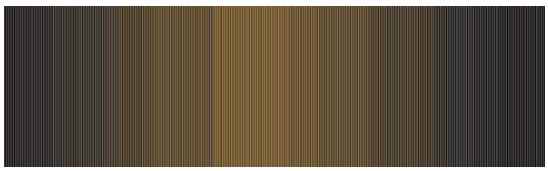


Figure 4 - Full year image for an east façade Location Cluses, France. (Generated with the first canvas)

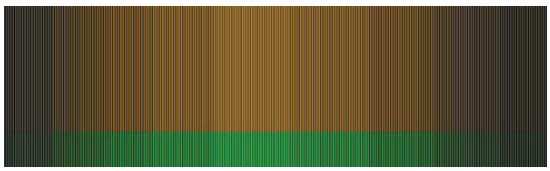


Figure 5 - Full year image for the automation of a solar protection on east façade. Localisation Cluses, France. (Generated with the first canvas)

Cluses, France (See Figure 3 and Figure 4).

We also generated the image for the automation of the corresponding solar protection (See Figure 5). For both graphic, the horizontal axis is for the minute of the year. The color code for the first graph is black for night, orange for direct sun and grey otherwise. The color code for the second graph is black for "apply automation rules for night"; grey for "apply automation rules for diffused light"; orange for "apply automation rules for day with high direct sun" and green for "apply automation rules for low illumination". For this automation, the vertical axis covers the range of values provided by a daylight sensor. Obviously, the BAS needed to run this automation was very easy to code. In addition, a human being who understands the canvas can easily read the image and explain how the bioclimatic façade will react to the weather conditions. However, nobody in our first test group – in-house individuals selected in the R&D and the Intellectual Property departments - was able to go any further than saying how the façade reacts at a given time for a given daylight. Even with the first graph that exposes a bioclimatic reality of the façade only, they were not able to give the orientation of the window. As our primary goal was to have a tool easy to assimilate, this first canvas did not work. Nevertheless, it was not a complete failure. We learnt several important piece of information. The first one was about size. We realized that the images drawn upon the canvas should remain constant in size and definition for the two axes. The change of colours was not as confusing as compared to the change of axis. Our very first graph was in fact a colored line with some weight so that we can clearly see the colours. Indeed, in our experiment everything was either constant (building location, shape and orientation) or a function of time only (sunrise, sunset direct sun and shadow). Therefore, there is no need for the vertical axis. However, several individual struggled to realize that the image translating the bioclimatic reality of the window and the one for the BAS were for the same window. As soon as we gave the same footprint to both images - to stay within the definition of the canvas we used a constant for the vertical axis of the bioclimatic image - people never asked us again why the images do not have the same size if they are for the same window.

The second key information is about the visualization of time. People did not see the evolution of direct sun exposure with this canvas. Everybody saw there was an evolution over the year, but nobody was immediately able to explain it with the variation of day length over the year. Actually, we saw that the relation Sun/Earth was not obvious for many people and the unusual appearance of the images added some complexity. No-one has been able to answer us at once how many black bands in the bioclimatic image of a window on a north façade in France for a leap year. The simple exercise of retrieving which bioclimatic image was for a north façade and which one was for a south façade of a cubical building located at Cluses, France, has been also very challenging for a lot of people.

We concluded that the canvas should be designed for human first and not for the building automation system.

Second Solution Tried

Recognizing that the Sun is one out of the three primal source of energy on Earth (solar radiation; gravity and geothermal) and the most important in true bioclimatic architecture, we based our second

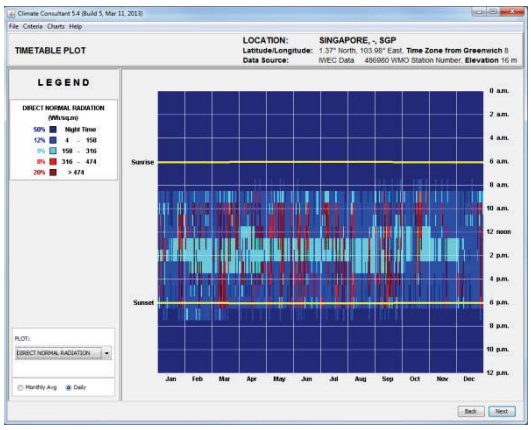


Figure 6 - Timetable Plot Direct Normal Radiation for Singapore
(Climate Consultant 5.4)

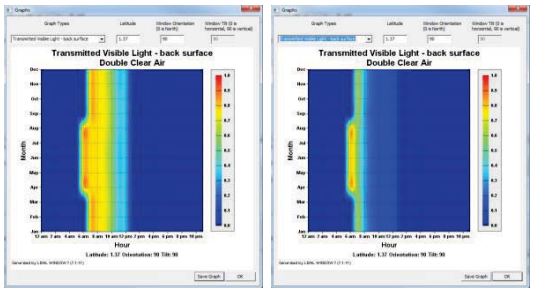


Figure 7 - Annual Optical Graphs for Complex Fenestration System on east facade at Singapore (Window 7.1.11.0)
(Left: Double Clear Air glazing)
(Right: Double Clear Air glazing with Interior Venetian Blinds at 5cm, slates at horizontal (A0))

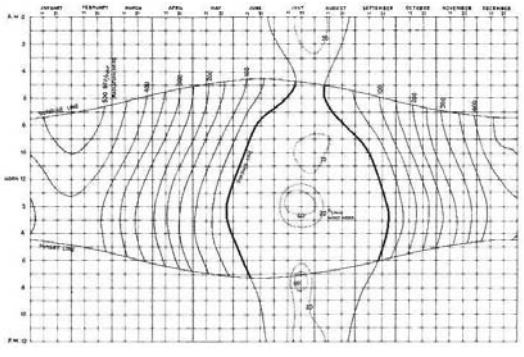


Figure 8 - The analysis of the New York, New Jersey area translated to a yearly chart.
(Olgyay, A., Olgyay, V., 1957, Solar Control and Shading Devices, Princeton University Press)
(page 22 – figure 49)

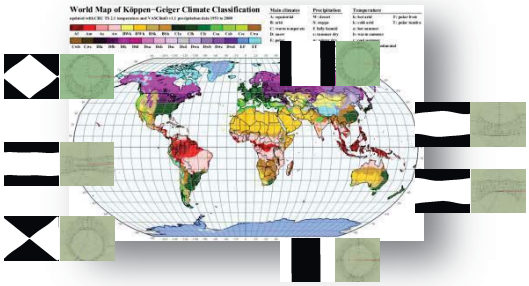


Figure 9 - Bioclimatic images Day/Night at different latitudes (Generated with our second canvas)

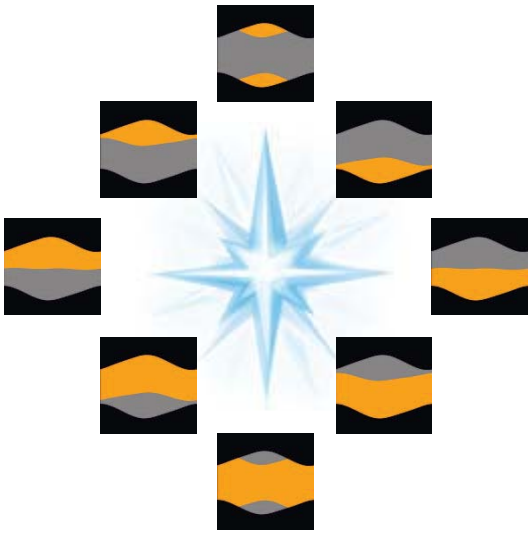


Figure 10- Bioclimatic image Night/Day-Direct Sun/Day-Otherwiwise by orientation at Lat. 40°N (Generated with our second canvas)

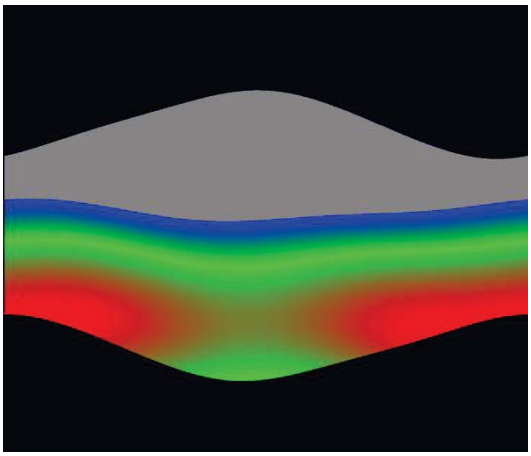


Figure 11 – Potential Irradiation Bioclimatic Image (Generated with the second canvas)

canvas on the yearly chart. The yearly chart is often used in software to display the solar energy (See Figure 6). However, it is also used to display other information such as the different parameters of complex fenestration systems (See Figure 7) or to perform the bioclimatic analysis of a region (See Figure 8). We chose to build our canvas with the day of the year on the horizontal axis going from left to right and starting on January 1st and the minute of the day on the vertical axis going from bottom to top and starting with 0 for midnight. This canvas gives in a glance the evolution of a data over one day as well as over several days.

For nearly two years, we have used this canvas to expose our sales forces to the bioclimatic reality of the projects they specify. Some of them take the images to explain to architects which kind of solar protection their design need. The key information we learnt regarding the canvas itself is:

- the evolution of the simple Day/Night image over latitude is very surprising for most people. (See Figure 9) It usually starts a discussion that is easy to end with a quick recall of how the polar circles, the two poles and the equator are defined.
- many professionals are surprised by the Day/Night – Direct Sun/Shadow images at one location for different orientations. (See Figure 10) They usually question the direct sun irradiation for a window facing north in the northern hemisphere and south in the southern hemisphere. Many are surprised how long façades oriented within north-north west and north-north east are touched by direct sun. For professionals who live above or below the tropics, the surprise is even bigger when the location is between the tropics. The corresponding discussion is usually quickly ended with a recall of how the tropics are defined.
- people do not seem to prefer one standard over another for the axes orientation but they are disturbed when we start with one convention and use another one during the negotiation. This has pushed us to write our own code to generate some images instead of using those generated with Climate Consultant and Window (In Climate Consultant the time axis starts the day at the top of the image and finishes it at the bottom. We, as in Ecotect, start the day at the bottom of the image and finish it at the top. In Window, the days of the year are on the vertical axis and the minutes of the day on the horizontal one). Keeping consistency from one graph to another is important not only for the data associated on each axis but also for the orientation of the axis, the ranges and the scales. We tried Rorschach shadow diagram scheme (Ekatzenstein, 2012). The canvas of this diagram also has the day of the year on the horizontal axis but the vertical axis represents the minutes of the day since sunrise (See Figure 12). The fact that a given hour is not a straight horizontal line has been very disturbing for the few in-house individuals who view the graph.

Regarding the analysis that can be done with the canvas we conclude that:

- the bioclimatic images work very well for our experts when they want to explain to non-experts how the sunrays touch the building and what does it means for the IEQ. Our sales forces are increasing their success rate when they use it to expose the need for a dynamic passive strategy to the stakeholders. We also clearly see that in this fragmented market, that is the building industry, teaching and explaining is still stronger than just proving. Bioclimatic images have more impact when they are supported by an explanation.
- there is a real added value in exposing the bioclimatic reality of a building in a 2D space-time rather than in the 1D space-time or even without the time dimension at all. Professionals are used to working with this latest kind of canvas. They use false colours images of their design to analyse it at a given instant to see the time dimension they create animations or series of independent images. This partially answers their real needs, as it is nearly impossible to detect any time-pattern this way. When data are plotted with only one axis dedicated to time (i.e. plot in a 1D space-time), it is not easy to point out any pattern with long periodicity compared to the step used for the time axis. The 2D space-time provides another axis to ease the discovery of two different periodic patterns. Considering that a building is operated 24/7-365, it justifies our choice for day as step for the horizontal axis instead of month as it is usually the case. For the vertical axis, we have to consider the Shannon-Hartley theorem. The granularity must be at least twice lower than the one of the BAS with a maximum corresponding at the simulation step defined in modern regulations (i.e. one hour). The logical choices are 30 minutes, 20 minutes, 15 minutes, 10 minutes, 5 minutes, 4 minutes, 1 minute or below. The choice we made - one minute - is mostly marketing driven. However, it's a good compromised between the time needed to generate one image, the size and the memory footprint of the image as well as how smooth the results are.
- when it comes to solar energy per unit area of façade, we have better results by exposing the direct sun irradiance coefficient (i.e. ratio of the irradiance on the façade to the direct sun beam irradiance) than the actual sun irradiance computed with the weather data. The first images (See Figure 11) is the one we would have if the direct sun irradiance was constant all the yearlong. It exposes the irradiance potential on a surface and makes obvious that the irradiance also

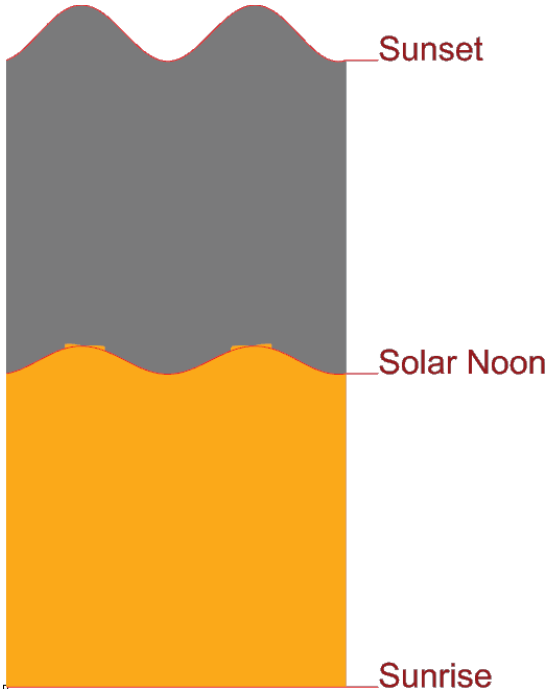


Figure 12 - Rorschach diagram for a east facing window at Singapore

depends on the angle of the solar beam incidence. With this potential irradiation bioclimatic image, many professionals realize they were not looking at heat gain the right way. It helps to point out where and when sun gains should be managed and how.

- there is by far more to be done with this canvas than it appears at once. To give only three examples: the subtraction of two potential irradiation bioclimatic pictures displays the impact an architectural option can have on the sun gains; the dynamic over the color scales during the daytime period in a potential irradiation bioclimatic image translates the need of a dynamic passive strategy; the range of colors in an irradiation bioclimatic image can be used to define the appropriate complex fenestration system. Until now, we have always been able to use a bioclimatic image to answer a request for explanation transmitted by our sales forces.

Regarding the BAS, although we have not launched any commercial offer able to exploit a bioclimatic image yet, we have successfully used them to define important parameters for our actual offers and we have several patent pending. For example:

- definition of zoning. The zoning consists to reduce the number of different behaviours for all the automated solar protections controlled by the BAS. We first create a bioclimatic image per automated solar protection. Then we sort the bioclimatic images in different group. Each group defines a zone.
- limitation of automatic moves per day. We gather together the moves that are too close to each other in the same column of a bioclimatic image.
- limitation of direct sun discomfort. We generate the potential irradiation bioclimatic images for surfaces in the field of view of the user. These bioclimatic images expose when there is risk of discomfort and how the specifications of the complex fenestration system must evolve. This method is used when we cannot invest in more elaborated but also time consuming simulation to quantify the visual discomfort.
- optimal position for sun penetration. We generate the potential irradiation bioclimatic image for each possible positions of the solar protection. To define the moves we stack the images together. We directly read the optimal position on the section of this volume made at the given day.

CONCLUSION

We have adopted a canvas to explain the bioclimatic realities of a building to stakeholders. We experienced it is more important for us to teach the fundamentals and explain the mechanisms than just providing results out of the blue. We understand this fact as consequence of the fragmentation scheme chosen by the building industry in order to face the always-increasing complicity in buildings. This scheme has led to the hyper-specialization of the professionals with a lack of whole building thinking that prevents business-as-usual to design not only true green building but also great buildings. We believe that IPD can solve the issue when the professionals – including academics - from all across the building industry are ready to discuss with each other's with a *Win-Win-Win* state of mind. To do so, each and every professional should have a toolbox adapted to his profile and role in the building industry. The canvas we chose has a key role in our toolbox.

We use a yearly chart as canvas to generate our bioclimatic images. These images are not tools per se but materials for our speech. A bioclimatic image exploits a color scale to display a data in the 2D space-time that translates the 24/7-365 operating time of buildings (the horizontal axis is for the days of the year. The vertical axis is for the minutes of the day). They are perfectly adapted to find patterns and to help stakeholders to understand how buildings interact with the surroundings all the yearlong. This is crucial when it comes to choosing the right passive strategies for a building.

As expert leaders for the worldwide leading manufacturer of actuators and controls for bioclimatic facades, we are in touch with stakeholders from all around the world. They

continuously present us with new challenges. We have always been able to use the canvas to generate the bioclimatic images needed to make our point.

We are also exploring how to use this canvas to code a building automation system. This would completely merge architecture and automation into one complete and true bioclimatic architecture. Several patents are pending but nothing is commercially available yet. Still, we are regularly exploiting the canvas to define key parameters for commercial projects.

We also plan to explore other ways of defining buildings. We will share any interesting results. That is one of our actions to promote the *Win-Win-Win* state of mind and *green* the world. However, we will never force other experts to adopt our tool. We think it is up to the experts of each field composing the building industry to define their own toolbox. Nonetheless, we are ready to help and this has been our motivation to write this paper.

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MULTI-OBJECTIVE OPTIMISATION OF SEMI-TRANSPARENT BUILDING INTEGRATED PHOTOVOLTAIC FACADES

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ABSTRACT

Multi-objective optimisation of semi-transparent building integrated photovoltaic (BIPV) facades can be challenging when aiming to find an overall balanced performance between conflicting performance objective. This paper is a further development of the design optimisation method proposed by Choo and Janssen (2013) which maximises overall energy savings of a typical office with a semi-transparent BIPV façade. It proposes the enhancement of the optimisation method by considering not just daylight autonomy as a factor for daylight savings but also considers daylight glare probability as an additional factor for a more realistic simulation scenario. A demonstration of this enhanced method is presented for a typical office façade in Singapore.

INTRODUCTION

As mentioned by Choo and Janssen (2013), the design of typical roof mounted photovoltaic systems only focuses on the amount of electricity generated. The design of semi-transparent BIPV facades in contrast has an impact on a wider range of factors, including heat gain and daylight penetration into the rooms in the building. To optimise the performance of such facades, optimisation systems that leverage on existing simulation tools for performance evaluation can be used.

This paper continues from the study conducted by Choo and Janssen (2013). In the paper, they proposed a three-phase method: 1) calibration, 2) optimisation, and 3) validation. The multi-objective optimisation considers three performance metrics, namely daylight savings, cooling load and electricity generation of the BIPV façade. The proposed method reduces the optimisation run time from 14 days for a base case to less than 3 days with the use of faster proxy simulations.

In addition to the existing three performance metrics used by Choo and Janssen (2013), this paper considers daylight glare probability (DGP) (Wienold and Christoffersen 2006) as another performance factor that affects the daylight savings within the multi-objective optimisation process. The section on optimisation method gives an overview of the proposed enhanced method and the section on demonstration presents the application of the method based on a typical office façade in Singapore. At the end, the paper concludes and highlights avenues for further research.

OPTIMISATION METHOD

The method consists of three phases (Figure 1): 1) calibration, 2) optimisation, and 3) validation. In the calibration phase, simulation models are selected and simulation programs are configured and tested. Simulations that are deemed too slow are replaced by faster proxy simulations, which are configured in a way where appropriate trade-offs are achieved between speed and accuracy. The optimisation phase makes use of the simulations within the iterative optimisation process in order to explore design variants with improved performance. Lastly, in the validation stage, the final designs from the optimisation phase are analysed and evaluated in more detail. In order to verify the performance improvements, slow simulations will replace all proxy simulations.

Calibration Phase

Semi-transparent BIPV facades affect energy savings in three distinct ways, namely daylight savings, cooling load and electricity generation of the BIPV façade. The enhancement to the method proposed here is the addition of daylight glare probability (DGP) as a reduction factor to daylight savings. This reduction factor is termed the glare coefficient in this paper.

Daylight savings is the amount of electricity saved by using daylight instead of artificial lighting in order to light a room to a set minimum illuminance level. Daylight autonomy affects the daylight savings, hence maximising daylight autonomy will in turn maximise daylight savings. On top of that, the enhanced method proposed takes into consideration a glare coefficient, α, as a reduction factor to daylight savings to reflect the reduction in daylight savings when blinds are drawn due to glare. The following

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equation defines the total electricity savings, which considers the glare coefficient:

$$E_S = E_G - C_L + \alpha D_S \quad (1)$$

where E_S is the total electricity saving ($kWh \cdot a^{-1}$), E_G is the electricity generated ($kWh \cdot a^{-1}$), C_L is the cooling load ($kWh \cdot a^{-1}$), D_S is the daylight savings ($kWh \cdot a^{-1}$) and α is the glare coefficient.

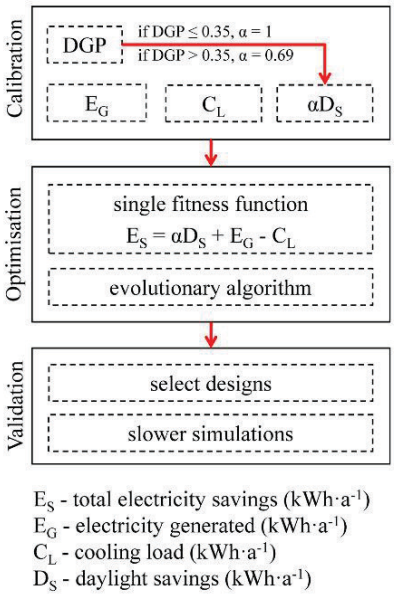


Figure 1: Schematic of three phases during optimisation process

Optimisation Phase

For the optimisation phase, the evolutionary algorithm consists of three key procedures, which includes development, evaluation, and feedback.

The development procedure will generate design variants using a parametric model. Typically, a Visual Dataflow Modelling (VDM) (Janssen and Chen 2010) system will define the parametric model. Genes in the geno-type are then associated with the parameters in the model.

The evaluation procedure will evaluate design variants. In this case, the evaluation procedure will calculate the total electricity savings, which includes the daylight savings, cooling load and electricity generation.

The feedback procedure will kill design variants that perform badly and reproduce design variants that perform well. The selection and reproduction can use a variety of different strategies.

Validation Phase

For the validation phase, the best designs that emerge from the evolutionary process are analysed and re-simulated. At this final stage, if possible, the slower but more accurate simulations should replace the proxy simulations. Performance characteristics of the final design variants can then be verified.

DEMONSTRATION

Design Scenario

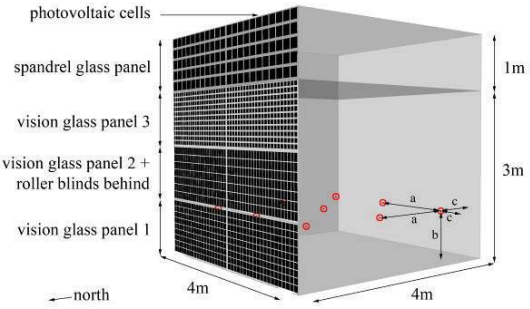
The experiment involves optimising the pattern of PV cells on a semi-transparent BIPV facade in order to maximise the total electricity savings. The PV pattern affects both the solar radiation and the daylight penetrating into the room through the glazing, and it will therefore have an impact on all three components of the electricity savings calculation: daylight savings, cooling load and electricity generation.

A typical north oriented office space for one person occupancy with 4 m (width) x 4 m (depth) x 3 m (height) is modelled for the experiment, as shown in Figure 2 (top). The facade is separated into four zones: vision glass panels 1, 2, 3 and spandrel glass panel. Each zone is independent from one another. Three genes such as cell height, cell width and cell spacing as shown in Figure 2 (bottom), define the PV cell pattern for each independent zone. Cell height and width vary from 5 – 15.5 cm at 0.5 cm steps but are independent from each other. Cell spacing varies from 0.5 – 5 cm at 0.5 cm steps. All the cells of the semi-transparent BIPV facades will be similar in shape. The pattern occupies a facade with a height and width of 4 m.

For this paper, a roller blind with an openness factor of 3 is modelled behind vision glass panel 2. It is only activated when DGP (Wienold 2009) is above 0.35 where glare is perceptible.

Software Tools

The main tool used is Grasshopper (Rutten 2011), a plugin for the Rhinoceros computer aided design modelling software (McNeel 2010). Grasshopper (Rutten 2011) is a VDM system that allows designers untrained in scripting to generate parametric models quickly. A number of specialist Grasshopper components are used for running optimisation algorithms and executing simulations.



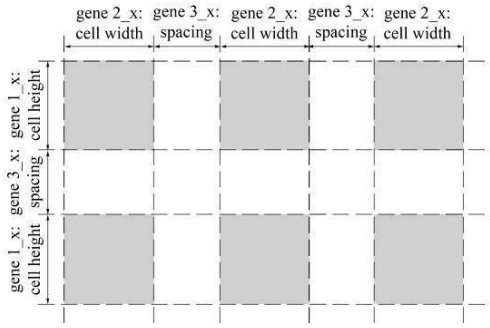


Figure 2 (top): Simulation model with sensors (a = 1.50m, b = 0.85m, c = 0.50m)

Figure 2 (bottom): Schematic of cell arrangement for semi-transparent BIPV façade with gene 1_x, 2_x and 3_x, where x is the glass panel numbers (1-3)

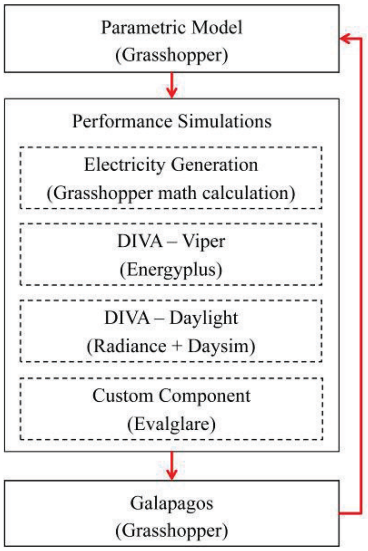


Figure 3: Workflow of different software tools for the optimisation process

For running optimisations, the Galapagos component is used (Rutten 2011). This component is an evolutionary optimisation solver, which can be used to optimise designs for a single performance criterion.

For executing cooling load and daylight autonomy simulations, the DIVA component is used (Jakubiec 2011). DIVA links to the simulation programs such as EnergyPlus (Crawley *et al*., 2001) which simulates cooling loads and Daysim (Reinhart 2010) which simulates daylight autonomy.

Both cases make use of an EnergyPlus weather data file (NREL 2012) for Singapore. The daylight autonomy is then used as a basis for calculating daylight savings.

An additional customised simulation component is developed within grasshopper to link to Evalglare (Wienold 2006). Evalglare is a radiance-based tool for glare simulation and analysis. The workflow of the different software for the optimisation process is shown in Figure 3.

Calibration Phase

For the calibration phase, the three components of the total electricity savings calculation will be explained below.

Electricity Generation

The annual electricity generation of a photovoltaic module can be simulated using EnergyPlus. In this research, we propose to use EnergyPlus, which has a simple model, as an alternative to the equivalent one-diode model (EnergyPlus 2011). The mathematical equation used is:

$$P = A_s \times f_a \times G_t \times eff_{cell} \times eff_{invert} \quad (2)$$

where P is the electrical energy produced by photovoltaic (kWh), A_s is the net area of photovoltaic module (m^{-2}), F_a is the fraction of surface area with active solar cells, G_t is the total annual solar radiation energy incident on PV array (which is set at a DIVA-calculated value of 561 $kWh.m^{-2}$), eff_{cell} is the semi-transparent BIPV facades module efficiency (which is set at 12%) and eff_{invert} is the average inverter efficiency (which is set at 90%).

In order to verify the accuracy of the simple model, a set of commercially produced photovoltaic modules (for which the electrical characteristics were already known) were simulated using both the equivalent one diode model and the simple model. A comparison is then made. In total, we carried out simulations for 16 different modules for the four different cardinal directions. The annual electricity generation was simulated with EnergyPlus for both models

(EnergyPlus 2011). After which, the trend-line of 64 pairs of results for the simple and the equivalent one-diode models were plotted using Microsoft Excel. The electricity generation for the simple model resulted in an R^2 correlation of 0.98. This shows that the simple model has a good correlation and is suitable as an alternative to equivalent one-diode model.

Cooling Load

The cooling load for the room can also be simulated using EnergyPlus. For simplification, the study considers the heat gain through the semi-transparent BIPV facades but not the internal heat gains from lights, equipment and occupants. Default materials from the material library in DIVA are used. With reference to Figure 2 (top), the walls, floor and ceiling are assigned as "adiabatic" and spandrel glass panel are assigned as "opaque spandrel glass".

A window module is defined to represent a typical 6 mm thick clear glass window with a U-value of 5.8, a solar heat gain coefficient (SHGC) of 0.82 and a visible transmittance (VT) of 0.88 (Pilkington 2010). For the photovoltaic cells, there are two different approaches with different trade-offs between speed and accuracy. The slower but more accurate approach to modelling the PV cells is to assign them as external shading elements. Each cell is assigned a solar reflectance of 0.1 and visible reflectance of 0.1. The amount of solar radiation affected by the shading from photovoltaic cells is calculated for each photovoltaic cell and for each time-step for an entire year in the simulation. Each time step calculation is different from the next because each value is dependent on the time and location of the sun. For each simulation, there are various external shading elements of different patterns with number of photovoltaic cells ranging from 156 to 4224. The large number of shading elements resulted in a relatively long time taken for the simulation to run, with the longest simulation taking approximately 30 minutes. This caused the optimisation of the base case, mentioned in the introduction, to run for almost 14 days.

Hence, in view of the time factor, a faster proxy simulation is proposed that uses a less accurate approach to the modelling of the PV cells. With this approach, the solar heat gain coefficient (SHGC) and visible light transmittance (VLT) for the facade are adjusted to take into account the effect of the PV cells. The equations for SHGC and VT used in the proxy simulation are:

$$SHGC = A_{pv}/A \times SHGC_{vg} \quad (3)$$

where SHGC is the solar heat gain coefficient of semi-transparent BIPV facade ($Wm^{-2}K^{-1}$), $SHGC_{vg}$ is the solar heat gain coefficient of the vision glass panel (which is part of the semi-transparent BIPV facade but without photovoltaic cells) ($Wm^{-2}K^{-1}$)

$$VT = A_{pv}/A \times VT_{vg} \quad (4)$$

where VT is the visible transmittance of the semi-transparent BIPV facade ($Wm^{-2}K^{-1}$), VT_{vg} is the visible transmittance of the vision glass panel (which is part of the semi-transparent BIPV façade but without PV cells) ($Wm^{-2}K^{-1}$), A_{pv} is the total area of PV cells (m^2) and A is the area of semi-transparent BIPV facade (m^2)

In order to check the accuracy of the proposed proxy simulation, 164 cooling load simulations for different BIPV facades were conducted using both the slow simulation and the proxy simulation. The trend-line for both the slow and proxy simulations were plotted using Microsoft Excel, and an R^2 correlation of 0.93 was calculated. This shows that the proposed proxy simulation for cooling load has a good correlation and is suitable as an alternative to the slower and more detailed cooling load simulation.

Enhanced Daylight Savings

In this paper, the enhanced daylight savings is calculated based on the daylight autonomy and daylight glare probability for the room, which can be simulated using Daysim and Evalglare (Wienold 2006) respectively. In this case, since Daysim is already an optimised simulation method (Reinhart 2010), the simulation can be executed relatively quickly with no need to create a proxy. For Evalglare, a customised Grasshopper component is created to simulate daylight glare probability and output into the evolutionary optimisation process.

Daylight Autonomy

A recent study on various lighting standards around the world by Halonen *et al.* (2010), found that minimum illuminance for interior spaces ranges from 200lx to 500lx. Hence, for the simulation of daylight autonomy, the minimum illuminance level of 500lx is set for the simulation. Working hours are set from 9:00 to 18:00. A 3 x 3 nodal grid of daylight sensors are drawn 0.85 m from the floor and 0.25 m away from the vertical walls as shown in Figure 2 (top). Since daylight autonomy is more critical for areas further way from the windows, only the last 2 rows furthest away from the windows of 6 daylight sensor nodes are used for the daylight autonomy simulation.

Default materials from the material library in DIVA are used for the simulation. Based on research done by Protogeropoulos and Zachariou (2010), a typical photovoltaic module has a reflectance of below 10%. Hence, a reflectance of 10% is assigned to the photovoltaic layer.

The following settings were used in DIVA/Daysim: ab = 2, ad = 1000, as = 20, ar = 300 and aa = 0.1, where ab is ambient bounce, ad is ambient resolution, ar is ambient resolution and aa is ambient accuracy. The detailed explanation of the settings is described in the Radiance manual.

Glare Coefficient

It is impractical to use an annual glare simulation for the optimisation process because of the long runtime per iteration. For example, it takes about 6 hours to conduct a base case annual glare simulation. Hence, a proxy simulation of using a fixed point in time glare simulation is proposed.

A custom Grasshopper component is created as a wrapper to Evalglare (Wienold 2006) in order to calculate the point-in-time glare within Grasshopper. Figure 4 shows a schematic of this custom Grasshopper glare component. Glare is measured as DGP. 0.35 > DGP is considered imperceptible, 0.4 > DGP ≥ 0.35 is considered perceptible, 0.45 > DGP ≥ 0.4 is considered disturbing and DGP ≥ 0.45 is considered intolerable.

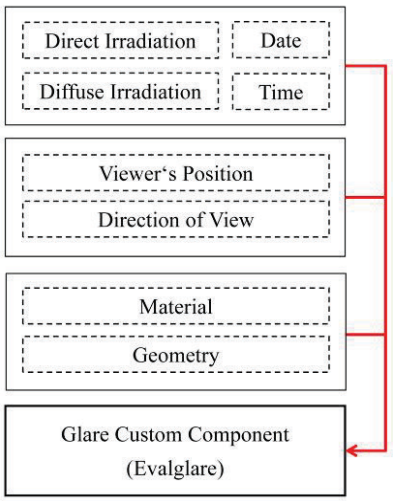


Figure 4: Schematic of custom Grasshopper glare component

To determine the point-in-time to use for the glare simulation, 20 runs of annual glare simulation are done for a range of selected design variations within the solution space of possible designs to determine the day and time which has glare for all the design variations. The point-in-time was found to be 21 June, 12:00PM which is the solstice. This day and time is used for the point-in-time glare simulation using the customised glare component to activate the roller blinds and reduce the daylight savings. The same 20 runs of annual glare are run with the roller blinds drawn down. It shows that for the entire year there is only imperceptible glare with DGP less than 0.35. In turn, if glare is eliminated for this point-in-time, glare for all other time in the year is also eliminated.

The reduction factor of daylight savings is represented by the glare coefficient, α, which is added as a factor to daylight savings, D_S shown in equation 5. This is to take into account the reduction of the daylight savings when the blinds are drawn due to the presence of glare. When the DGP for point-in-time glare is greater than 0.35, the roller blinds are drawn affecting the daylight savings. Enhanced daylight savings, $D_{S'}$ in equation 5 can be reformulated to equation 6:

$$D_{S'} = \alpha D_S \quad (5)$$

$$D_{S'} = (\alpha D_A/100) * LPB * FA * WH \quad (6)$$

where D_S is the daylight savings ($kWh \cdot a^{-1}$), $D_{S'}$ is the enhanced daylight savings ($kWh \cdot a^{-1}$), D_A is the simulated daylight autonomy (%), LPB is the lighting power budget ($kW \cdot m^{-2}$), FA is the floor area of simulation model (which is 16 m^2), WH is the working hours per year and α is the glare coefficient.

LPB is set based on the Code of Practice for Singapore (SPRING 2006) which recommends an LPB for offices of 0.015 $kW \cdot m^{-2}$. WH is set based on a 5-day work per week with nine hours of work per day, which results in 2,340 hrs per year.

As shown in equation 6, glare coefficient, α is a factor to D_A. Hence, α can be defined as the scale factor of reduction of daylight autonomy, D_A. Daylight autonomy is simulated using 125 selected designs with and without the roller blinds on 21 June, 12:00PM and plotted using Microsoft Excel. The regression coefficient of 0.69 from the linear regression is then appropriated as the glare coefficient. The coefficient of determination R^2 is 0.9, which displays good correlation.

Optimisation Phase

Galapagos is executed with a population of 30 and initial boost of 2%. The maintain level is set at 10% and inbreeding at 75%. The system was executed on

a single computer with an i5 Intel core CPU of 3.5GHz with 8GB of RAM, on 64 bits Windows.

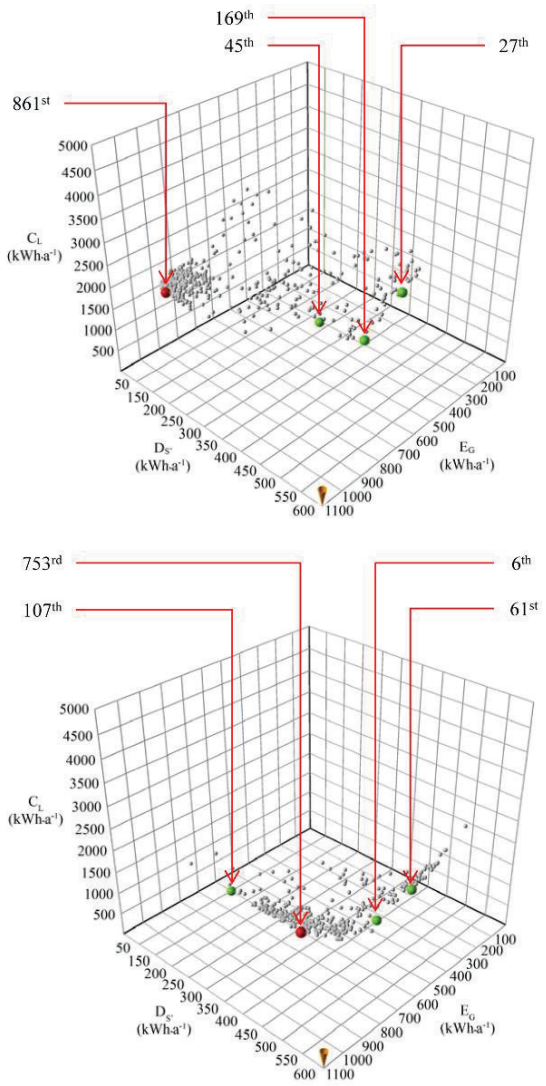


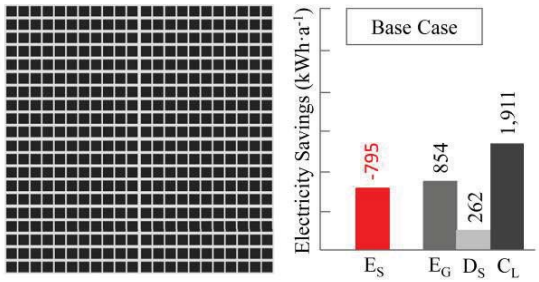
Figure 5 (top): 3D plot of results for optimisation with enhanced daylight savings

Figure 5 (bottom): 3D plot of results for optimisation without enhanced daylight savings

The optimised design was found at the 861st iteration as shown in Figure 5 (top). The orange point represents the ideal design performance and the red dot represents the design with the best performance. While the optimisation without daylight savings takes 2 days, 17 hours, the computational time increases to 14 days 17 hours when including this fourth variable. This shows that for multi-objective optimisation, the addition of performance objectives to the optimisation process can increase the run time drastically. However, evolutionary algorithm is useful in simplifying the task of finding an overall balance performance for semi-transparent BIPV facades, especially where conflicting performance objectives may prove to be challenging to explore manually. In addition, it also allows the designer to review other designs along the Pareto front. The Pareto front consists of designs that have good overall performance but with different performance trade-offs. This method provides the designer the choice to select the designs they better prefers and have a good idea on the pros and cons of picking it in relation to its various performance objectives.

Validation Phase

In the final validation phase, the designs from the Pareto front were selected and analysed. In order to verify the performance improvements, the proxy simulations were replaced with the original simulation used in the base case and the designs were re-simulated. In all cases, the results from the original simulation confirmed the performance improvements with respect to the base case. Additionally as shown by both the annual glare simulation with and without roller blinds, the glare is eliminated for the entire year for the optimised design with enhanced daylight savings. The proposed design method with enhanced daylight savings maybe more realistic in consideration but the performance values are not considered as absolute. The performance values should be used as a relative comparison to a base case, as shown in Figure 6 (left).



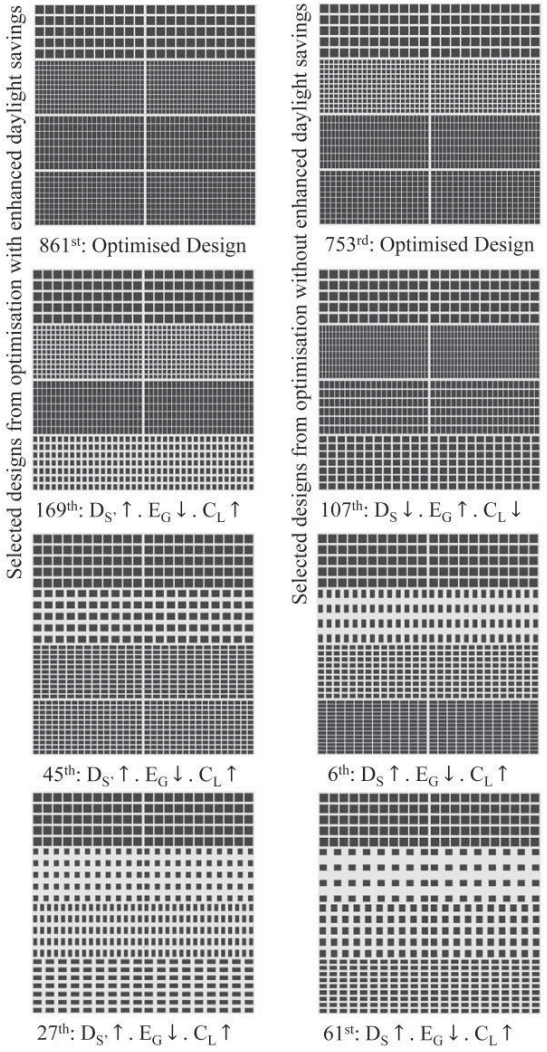
E_S - total electricity savings (kWh·a⁻¹)
E_G - electricity generated (kWh·a⁻¹)
C_L - cooling load (kWh·a⁻¹)
D_S - daylight savings (kWh·a⁻¹)

Figure 6 (left): Base case design with standard PV cell arrangement.

Figure 6 (right): Barchart of E_S, E_G, D_S and C_L for base case design.

Figure 7 and 8 shows that the optimised design with enhanced daylight savings showed an overall improvement of 15% of the total electricity savings over the base case design shown in Figure 6.

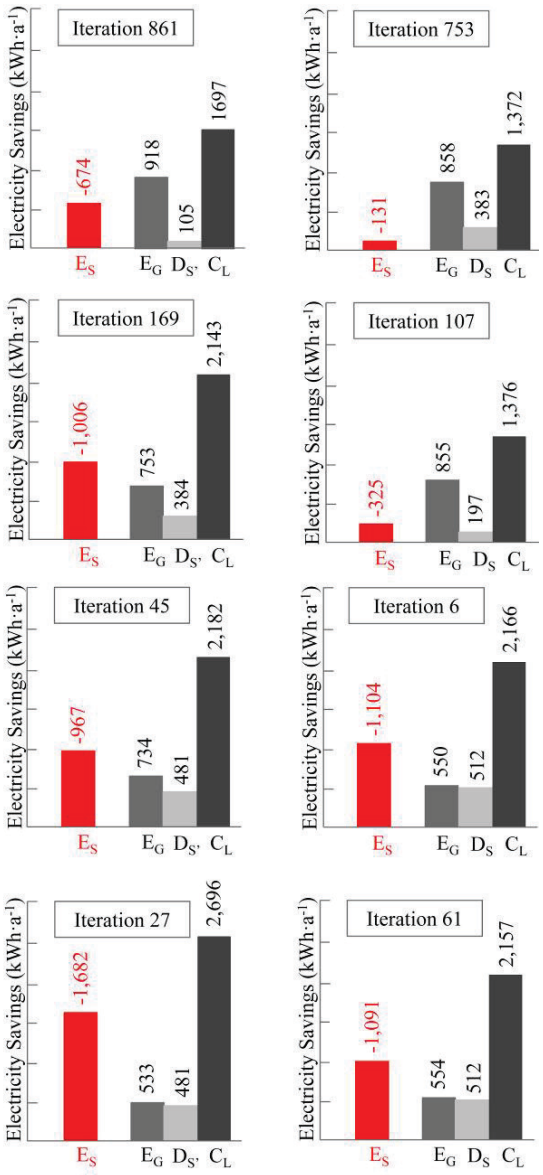
Comparing with the optimised design without enhanced daylight savings, an overall improvement of 84% of the total electricity savings over the base case design was calculated. This shows that without the enhancement, there is an overestimation of 69% of overall electricity savings. Hence, the optimisation with enhanced daylight savings gives a more accurate performance closer to the real scenario with occupants drawing down the blinds when there is glare.



E_S - total electricity savings (kWh·a^{-1})
E_G - electricity generated (kWh·a^{-1})
C_L - cooling load (kWh·a^{-1})
D_S - daylight savings (kWh·a^{-1})
$D_{S'}$ - enhanced daylight savings (kWh·a^{-1})

Figure 7 (left): Optimised design and selected designs along Pareto fronts of both optimisations with enhanced daylight savings

Figure 7 (right): Optimised design and selected designs along Pareto fronts of both optimisations without enhanced daylight savings



E_S - total electricity savings (kWh·a^{-1})
E_G - electricity generated (kWh·a^{-1})
C_L - cooling load (kWh·a^{-1})
D_S - daylight savings (kWh·a^{-1})
$D_{S'}$ - enhanced daylight savings (kWh·a^{-1})

Figure 8 (left): Performance bar charts of optimised design and selected designs along Pareto fronts of both optimisations with enhanced daylight savings

Figure 8 (right): Performance bar charts of optimised design and selected designs along Pareto fronts of both optimisations without enhanced daylight savings

Figure 7 and 8 shows a comparison of the best performance with three other betters designs along the Pareto front for optimisation using both enhanced daylight savings and non-enhanced daylights savings.

The designs for both optimisations using with and without enhanced daylight savings show that, as the façade gets more porous, more daylight is allowed into the office and the daylight savings increases but electricity generation decreases and cooling load increases due to increase in the solar heat gain.

CONCLUSION

The enhancement of the design method for the multi-objective optimisation of semi-transparent BIPV facades was proposed in this paper. The enhanced daylight savings within the optimisation process provides a more realistic scenario for the optimisation, which considers not just the amount of usable daylight within the space but also the possible reduction of daylight savings due to glare. However, this will cause a significant increase in the runtime compared to the method proposed by Choo and Janssen (2013) without the enhanced daylight savings. Although this enhanced design method is not appropriate for use in early design stage, it does simplify the task of finding an overall balance performance for semi-transparent BIPV facades, especially where conflicting performance objectives may prove to be challenging to explore manually. However, the absolute run time of 14 days and 17 hours for the optimisation process is considered long in the early stage design for designers where the design process is fluid and fast, and decisions for the design iteration are made quickly. If this method is adopted during early stage design, we need to apply additional proxy simulation techniques to reduce the run time of the optimisation process.

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CREATING BUILDING SPACE FOR FARMING AND MARKET IN JAKARTA

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ABSTRACT

Jakarta's population continues to increase at an alarming rate and will continue to urbanize, which is expected to create a lot of urban problems. More than 9.6 million people live in Jakarta, and it makes Jakarta as one of the densest cities in the world. As the capital city and the main economic sector in Indonesia, the rapid development and the uncontrolled land conversion will create major problems in the future. The concept of compact city is starting to be implemented as the new mix use buildings and central business district are starting to spread out through the city. Elkin (1991) also stated that the idea of compact city is to provide a concentration of socially sustainable mixed uses that will concentrate development and reduce the need to travel, thus reducing vehicle emissions. According to Indonesia Statistics Bureau, Jakarta has the highest monthly average expenditure per capita, and almost 40 percent is spent on food consumption. At some stage it will create agricultural crisis, and Jakarta will depend on other areas to supply the food to the city (imported food sources). The uncontrolled land conversion will force agricultural industries to move further away to the countryside. Good transportation is required, but it also causes more problems such as higher price for food, air pollution and traffic jam. Strategies need to be taken to ensure food safety in the cities; controlled indoor environment agriculture and urban farming are some of the strategies that would help the city, so it can produce and supply its own food and creating sustainable lifestyle. This paper will look into the possibilities of creating the building space for farming and market in Jakarta, which would support food production for the people in Jakarta.

INTRODUCTION

Jakarta covers a land area of 662,33 km^2. It has a population of 9.7 million people, making it one of the densiest cities in the world. The conversion of land in Jakarta will further reduce the amount of food production, creating higher imported and produced food outside Jakarta. In order to ensure food safety, immediate actions and strategies need to be taken. To name an example, urban farming can be a response to overcome the skyrocketing food prices in Indonesia. As urban farming has received a lot of support by the government as well as the private sectors, it may develop sufficiently to offer viable alternative livelihood options for a lot of impoverished and disadvantaged communities in the coming years. The land conversion in Jakarta is mostly caused by the demand of housing. According to Directory of Housing Development Cipta Karya (2006), the need of housing every year is up to 800.000 units. To overcome this problem, the government has built vertical housing flats to provide the demand of housing especially for people with social low economic class since 1984. In 2013 the Government of DKI Jakarta has planned to ensure the availability of residential and public spaces that are feasible and affordable for the people in Jakarta. The Government is encouraging people to move into vertical housing, by building a super block consisting of a vertical housing (flats), public spaces such as parks, markets, and health care centers for lower middle-class citizens.

COMPACT CITY CONCEPT

Ebenezer Howard had a breakthrough in the organization of urban space with the concept of Utopia Decentralization, or city that is not centered in one place, but spread evenly over the entire city in order to have a more harmonious relationship.



Figure 1. The Three Magnets
(Ebenezer Howard, The Three Magnets. No.1, 1902, in Garden City of Tomorrow)

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The Three Magnets, Howard thinks that the concept is to combine all the positives of the Town and Country Becomes Town-Country. It has been developed to present a concept or as a Mixed-Use or Compact City.

Elkin (1991) stated that the problem of, and search for solutions for, cities in the developed world are the focus of his book, in particular the concept of the compact ctity. There is a strong link between urban form and sustainable development, but it is not simple and straightforward. It has been suggested that a sustainable city must be of the form and scale appropriate to walking, cycling and efficient public transport, and with compactness that encourages social interaction. The theory is to an extend premised on urban containment, to provide a concentration of socially sustainable mixed uses, that will concentrate development and reduce the need to travel, thus reducing vehicle emissions. The promotion of the use of public transport, traffic calming, walking and cycling are often cited as solutions (Elkin 1991; Newman 1994). Further reductions from harmful emissions might also accrue from more energy efficient land use planning, combined power and heating schemes, and energy efficient building (Nijkamp and Perrels, 1994; Owens, 1986; Owens, 1992). From those statements, there are several points which mentions that the compact city or the small-scale mixed uses are related to sustainable design. And the first priority in sustainable design is efficeincy, like fuel, land and energy efficency, therefore the building is become more independent.

KEBON KACANG VERTICAL HOUSING & URBANG FARMING IN JAKARTA

To implement the concept of compact city and also to accommodate the needs of housing and farming for the city of Jakarta, we could look at one of the example of vertical housing that could provide a housng, farming and market under one roof. Kebon Kacang vertical housing is located at Kebon Kacang in Central Jakarta. It is one of the first projects of vertical housing in Jakarta in 1984. It is built to move the slums residence around Kebun Kacang which at that time si facing out an eviction. Until now the building is still standing, but the building condition is at a poor state. Kebon Kacang vertical housing need to be rejuvenated to fulfill the Government's plan to create a super block to accommodate the residents needs from green open spaces, health facilities and markets.



Figure 2. Kebon Kacang Housing
(Syarifah Nur Aida)

The development of urban farming in Jakarta is rapidly increasing. The private sectors and a number of local communities are actively transmitting this positive virus to Jakarta residents. Many residential areas have begun to realize the importance of urban farming in Jakarta. An example is *Kampung Rawajati,* which is located in the area of Pancoran, South Jakarta. The local government now refers this place as an Agro tourism village. There you can see hundreds of plants, ranging from medicinal plants, productive plants to ornamental plants grown independently by people who are committed to create a green environment. Furthermore, *Kampung Rawajati* residents have also implemented a waste recycling system to its marketing waste, which makes this region as a pilot area for other regions in Jakarta.



Figure 3. Kampung Rawajati
(Ruang Hergiawan)

Creating housing, farming and market space under one roof is one of the strategies that could be used by the Government to excecute its plans to create a superblock especially for the low-income families. Therefore the concept of compact city and sustainability issues can also be implemented into the

future project of vertical city housing in Jakarta, such as the Kebon Kacang vertical housing.

VERTICULTURE FARMING IN KEBON KACANG VERTICAL HOUSING

Verticulture is agricultural farming systems that is done vertically, both indoors and outdoors. Vertical cultivation system or multilevel is suitable for green concept for urban areas which have limited land for greeneries or farming. For example, generally on one square meter of land can be used to grow only up to 5 plants, but with use the verticulture planted crops system, can reach up to 20 plants. Verticulture also can increase agricultural output to ten times or even more.

According to Pujo (2006: 425), there are seven advantages of verticulture farming. They are:

1. The production quality is better and cleaner.
2. Higher production quantity and continuity of production can be sustained.
3. It can be used as a commercial sector, either directly or indirectly.
4. It can be used as a source of medical plants.
5. It will increase and improve family nutrition.
6. There is efficiency of land, fertilizer, water, seeds, and manpower.
7. It will eliminate stress or reduce the burden of mind.

Pujo (2006: 425) also stated that verticulture also has its disadvantages. They are:

1. It is prone to fungal attack.
2. The initial investment required is quite high.
3. If it uses a plastic roof, it must be watered every day.
4. It needs stairs or a special tool that can be climbed for maintenance and harvesting on the upper floor.

According to Ir. Niti mulyono Sapto, educational staff in the Faculty of Agriculture Gajah Mada University, clay, bamboo, or plastic tubes can be used as the types of verticulture pottery. These types of pottery are suitable for small-trunked plant vegetables, such as lettuce, mustard greens, cabbage, flowers, celery, or spinach (Gede: 2012). The verticulture systems also have different characteristic, they are:

1. Vertical verticulture: Usually this type is in the form of sturdy containers shaped columns standing upright on land.
2. Horizontal verticulture: This type is in the form of shelves or stair rise pots.
3. Hanging verticulture: This type is commonly seen in the form of pots or containers tied by a rope / wire and hung on the roof.
4. Arrange verticulture: This type is similar to the vertical verticulture. It differs only in the container and planting medium that will be used.

With the limited land available in Kebun Kacang vertical housing, the use of verticulture system can be applied easily. The verticulture farming can be done on the top floor (roof), because of the land limitation on the ground floor. The placement on the roof for the verticulture plants is also important factor, because of the sunlight that is important media for growing plants/ crops. With the placement of farming on the roof, we would have a lots of space available to be used as urban farming using verticulture system, and it is the best place to receive the availability of sunlight, especially in Jakarta's climate condition.

It is important to list the kind crops or plants that can be grown in Jakarta. Therefore the Government or developers can predict what kind of plants that can be harvested, and used for daily uses and consumption, especially for its residents. According to the Central Bureau of Statistics, Jakarta has an average temperature of 27.35 celcius and an average humidity of 74.25%. By comparing the growing requirements of the plants to the climatic conditions in Jakarta, then there are 8 plants can be cultivated in Jakarta. Of the 8 plants, the average require full light intensity in order to grow optimally. In science agriculture, a full light intensity is 6-8 hours sunlight exposure per day, while the limited full light intensity is 4-6 hours sun exposure per day.

Table 1
Plants that can be grown in Jakarta

PLANTS	TEMPERATURE (CELCIUS)	HUMIDTY (%)	LIGHT INTENSITY
Chilli	18-30	60-80	4-6 hours
Cayenne pepper	18-30	60-80	4-6 hours
Cucumber	21-30	80-85	4-6 hours
Paprika	21-27	80	4-6 hours
Kale	20-32	80-90	6-8 hours
Turmeric	19-30	60-80	6-8 hours
Ginger	19-30	60-80	6-8 hours
Galangal	25-29	60-80	6-8 hours

CONCLUSION

Creating housing, farming and market spaces in a vertical housing complex is certainly creating positive effects for Jakarta and its people. The residents could use the harvested plant to be used on daily basis. The harvested plant could be sold to other people in the area, so it would generate a positve locality from the economy point of view. The

comprehensive building for housing and farming could generate an economic stability and also creating positive impact to the environment. An urban farming concept certainly can be applied into the development of vertical housing in Jakarta, especially for the low-income families, where the Kebon Kacang vertical housing could be a prefect example that an urban farming concept could benefit its residents.

In the future, the study that can be done to follow this paper is to determine the other location within the site to create a farming spaces. It is also important to calculate the area that can be used for farming, and how much the plants/crops production that can be harvested. Therefore, the farming can be optimalized, and all the residents would have sufficient amount of foods from the farming spaces.

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RECLAIMING BACKLANES – ADDRESSING ENERGY EFFICIENCY, OUTDOOR COMFORT AND URBAN SPACE

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ABSTRACT

The façades of the shop houses in Rochor and Chinatown shine brightly and in full colour, but as soon as we step behind, into the backlanes, we are met by heat and noise from hundreds of split type air-conditioners. Backlanes in low-rise shop house typologies are generally utilised for support activities of the major economic activities on the main streets such as waste disposal and delivery. This is also where we find today batteries of air-cooled split type condensers that are inherently energy inefficient.

We suggest a novel technical solution, the *heat bus system*, that not only reduces energy use by 50% but also ameliorates the thermal microclimate by introducing water-cooled condenser connected to a central cooling tower, increasing the thermal comfort for pedestrians. It can also used as a trigger for architectural and urban design interventions that upgrade the backlane qualitatively and transform the backlane into a space that fosters social encounters and new economic activities. The nature of the shared infrastructure can be utilised to re-evaluate the neighbourhood, how to increase its value for occupants and owners.

The suggested design variation is a prototypical example of applying the *heat bus system* to a horizontal setting of a backlane. Combined with vertical high-rise solutions, this system may be adapted to any kind of urban typology in the tropical climate.

INTRODUCTION

The urban landscape in Singapore has been changing drastically over the last 50 years. Economical pressure and strong believe in modernistic urban design has led to the reshaping the city in the vertical dimension; high-rise buildings are the norm for housing (HDB and condominiums) and for commercial buildings and even industrial facilities. The low-rise shop house typology is a typical feature of the South-East Asian context. As a mixed-use typology, the front of the house, looking towards the main road, is used as commercial space while the back and the upper storeys are used as residential spaces. While high-rise construction as the only solution to more efficient land use has been contested, the pressure to densify these areas vertically and exploit the gained space economically is ever increasing. As outlined by the Government, the population may rise up to 6.9 Mio by 2030 [1], increasing spatial demand in the centre and periphery of Singapore.

The hot-humid climate in Singapore is characterised by average daily maximum temperature 31 ºC and an average relative humidity of 84% [2]. This environment has made air-conditioning one of the most important technologies for every day life in Singapore. In 2007, 75% of all households had air-conditioning, a tendency certainly rising [3]. Office spaces without air-conditioning are inconceivable with the comfort expectations of today. Modern office buildings may have centralised air-conditioning system but the majority buildings, new-build and retrofit, are cooled with split type systems. This standard design paradigm sometimes leads to inefficient configurations like in Figure 1. Air-conditioning is responsible for about 50% of the energy consumption in buildings and is thus a major contributor to anthopogenic carbon emissions [4].



Figure 1: Array of split type condenser units covering entire façades – here at 3 out of 4 sides.

The heat removed from cooling and dehumidifying the indoor spaces needs to be rejected to the environment. As a result, there is a large scale heating effect of the environment, as anthropogenic contributions to the urban heat island effect [5]. There is however also an influence on the local microclimate around the condensers, with detrimental effects on the performance of the air-conditioners.

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Analysis from measurements on a high-rise building are currently being published, showing a reduction in efficiency for an increase in floor number.

Heat exhausted from air-conditioning is not only a problem for the performance of the technical equipment, it also affects thermal comfort in outdoor urban spaces. While surveys show that people will accept higher air temperatures in outdoor spaces than inside [6], locally elevated temperatures from waste heat from air-conditioning clearly affect the pedestrian comfort. Figure 2 depicts a rather unusual self-made solution to deal with this situation, detrimental to the airflow of the condensing unit and thus to the performance of the air-conditioner.

Non motorised transportation like walking is limited in Singapore through the exposure to heat and rain in general. In this particular setup the increased temperature influences the pedestrians choice of movement away from the backlanes to the main road where cold air escapes through the open doors of the shops.



Figure 2: Self-made solution to stop direct impact of rejected heat blown at pedestrians at head height.

The backlanes of shophouses are generally economically underutilised or set up with support functions for the major activities of the main streets only. Some are still used for delivery of goods and collection of waste, they are now also spaces of waste disposal from air-conditioning: heat and noise. In times of high spatial demand, these backlanes represent valuable urban space to be used for social encounters, economic activities and non motorised transportation. An example that points into a similar direction with qualitative upgrade is the backlane of China Square Central (see Figure 3).



Figure 3: Backlane transformation in China Square Central.

Surveys in the backlane network in Little India and Kampong Glam show alternative uses where the backlane is transformed, on varying private – public scales such as building stock adaptation and new entrances, eating houses, manufacturing and private backyards (see Figure 4).



Figure 4: Examples of backlane transformations.

Our project investigates the potential of changing the design of these cooling systems by introducing the *heat bus system*, which will not only make the air-conditioning systems much more energy efficient but will also make the space more quiet, comfortable and usable. Combined with intervention regarding architecture and urban space, this project evaluates a prototypical design paradigm for backlanes in low-rise neighbourhoods of the tropics.

HISTORICAL DEVELOPMENT OF SHOP HOUSES AND BACKLANES

Shophousese are a common building type in cities of the Southeast Asian region. They are low-rise row houses with a sheltered arcade facing the main street. While their width is narrow they can stretch very deep into the land lot. Inner courtyards, jacked roofs and partition walls that were partly permeable allowed for good natural ventilation. Traditionally, a family business was run on the ground floor, while the owner lived on the upper floors. In the 19th century shophouse rows in Singapore were built back to back with the main entrance as single access. This proved insanitary as night soil (human waste collected in a bucket) and other waste had to be carried though the main hall and posed a safety risk in case of fire. A solution were the backlanes introduced since the 1920s [7], which provided access to the shophouses from the rear (Figure 5).

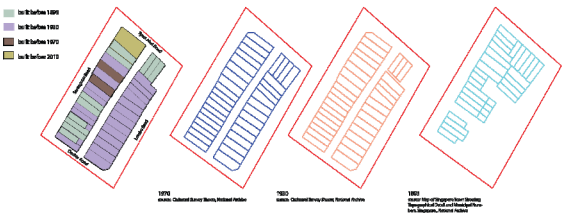


Figure 5: Shop house development, rough estimate of building ages

Construction of new shophoues in Singapore stopped in the 1970s. Maintenance, upgrading and conservation shifted in the focus of attention. Shophouses are still occupied by individual users and house shops, small traders, offices and hotels. Few are residential and even fewer maintain their mixed use character. The vernacular ventilation system is dysfunctional in most of the retrofitted shophouses as the original permeable partition walls do not satisfy modern needs of sound proofing and most of the inner courtyards are today covered with roofs. As a result most shophouses are air-conditioned. While most studies on shophouse districts are concerned with improving the design of the main facade and activities around the street façade [8], little attention is dedicated to the upgrading of the backlanes, where heat condenser units are placed and humm noisily and heat up the space.

The larger area of Rochor has ca 67'874 sqm (730'589 sq ft) of backlanes. With an average retailprice of 3'199 SGD/sq ft for shop houses in Rochor (propertyguru.sg), these areas represent significant assets.



Figure 6: Backlane as disposal space for waste, heat and noise

TECHNOLOGICAL CONSIDERATIONS: THE LowEx PARADIGM FOR AIR-CONDITIONING

The majority of measures to reduce energy use in buildings focus either on reducing or eliminating the need for cooling in the first place or on increasing the efficiency of the equipment used to provide cooling. Under the LowEx paradigm, a systems approach based on exergy analysis, the aim is to find the components or linked groups of components that have major impacts on the overall system performance [9]. Critical to the overall performance is the temperature lift of the cooling system, i.e. the temperature difference between the emission equipment like the fan-coil unit inside the space and the heat rejection system like the air-cooled condenser unit outside. Equation (1) describes energy performance with the Coefficient of Performance (COP), the amount of cooling provided to the space divided by the needed work input:

$$COP_{cooling} = Q_c / W = g * T_1 / (T_2-T_1) \quad (1)$$

Qc is the heat removed, W is the work consumed by the chiller, g is the exergetic efficiency of the chiller as a fraction of the ideal Carnot efficiency and T1 and T2 are the temperatures of the cold (building system) and the hot reservoir (environment). A lower temperature T_2, the temperature at which heat is rejected to the environment, will increase the efficiency of the overall system, independent of the internal efficiency of the cooling machine used. In a study looking at heat sinks for Singapore, the evaporative potential of non-saturated air, e.g. in an evaporative cooling tower, has shown the best performance, despite the very high humidity in the tropics [10].

As an alternative to the current solutions with air-cooled condensing units, we suggest the *heat bus system* comprising of distributed water-cooled condensing units, a central evaporative cooling tower and a hydronic network that connects these elements (see Figure 7), described in detail in [11].

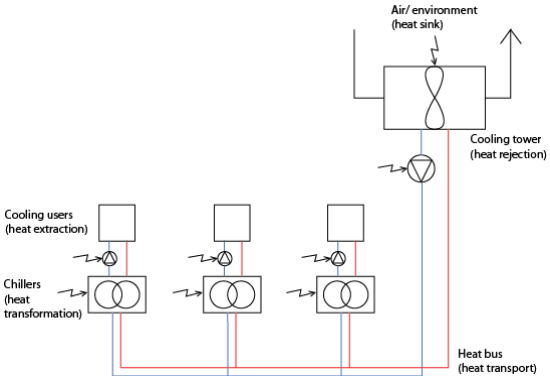


Figure 7: Heat bus system with main elements

In this way, the different chillers benefit from lower condensing temperatures and need less energy input. Unlike in centralised systems with large chillers, this heat bus moves heat at temperatures similar to outside air temperatures. The thermal heat loss becomes so small that insulating the pipes becomes unnecessary, allowing a very simple hydronic network to be built [11].

The additional pumping energy is very small compared to the gains in efficiency, as has been shown for the vertical implementation in a residential high-rise setting [11]. We have extended the application of this system into the horizontal dimension, linking together different houses in a neighbourhood or along a road with this heat rejection network.

REDESIGN FOR ROCHOR

Current situation: exemplary backlane

We chose the backlane between Serangoon Road and Lembu Road for this redesign exploration (see Figure 8) as an example that could be adapted to many other low rise settings in Singapore and beyond.



Figure 8: Focus area: backlane in Rochor+, between Serangoon Road and Lembu Road

There are two rows of shop houses, see Figure 9 and Figure 10, in quite diverse states, with different historical background (Figure 5). Very clearly visible, the back side is completely different from the front of each row of shop houses. While the front side is kept in order and/ or was restored, the façades on the back side do not seem to be taken care of.



Figure 9: Serangoon Road side - Front and Back



Figure 10: Lembu Road side - Front and Back

Most of the shop houses on Serangoon Road are used as shops – clothing, shoes, knick knack – some of them also on the upper floor. Mustafa has a subsidiary mall across several of the houses. On Lembu Road, there are several restaurant, grocery stores and shops. On both sides, there are a couple of hardware stores.

The air-conditioning equipment, the split type condensers, are mostly mounted on the façades of the backlane, Figure 11.



Figure 11: Typical arrangements of split units in backlane.

New design solution: heat bus system

By spatially up-grading the backlanes, the urban fabric of this neighbourhood becomes more open and less private. A gentle renovation enables the opening of the back façades especially on ground level. By becoming more public the block formulated by the two shophouse-rows becomes more porous, thus connecting Serangoon Road with the square. Bigger openings and windows in the façades of the backlane visually and physically invite visitors and passers-by to dwell and decelerate.



Figure 12: View of design variation, backlane of Serangoon Road.

The shophouse structure remains intact and visible, even the proposed volumetric additions respect the small scale of the neighbourhood. In this particular case, a four-storey building formulates the head of the row and integrates within the context of the Serangoon Road. Still the hierarchy from front to back remains intact, because of the mainly non-motorised pedestrian character of these backlanes, which would be underlined by simple groups of trees and shaders protecting dwellers from the natural elements.

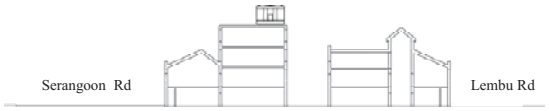


Figure 13: Section of design variation.

The existing shops and restaurants would be complemented by coffee shops and ateliers as well as other small-scale commercial activities. This spatial strategy can be adjusted and applied to other backlanes in the study area and other neighbourhoods.

Based on the distribution of the air-cooled split units and the respective cooling demand, new water-cooled units were placed accordingly. Two different models regarding capacity were assumed, 10 kW and 20 kW cooling capacity. There is still heat generated from the compressor due to internal irreversibilities but the amount is so small that the units may even be placed indoors, as long as they are ventilated.

A cooling tower of 769 kW heat rejection capacity was chosen to reject heat from all cooling units, assuming 70% of simultaneity of the total installed cooling capacity. The cooling tower is placed on the new 4-storey volume, increasing temperature and humidity of the ambient environment at the highest possible point.

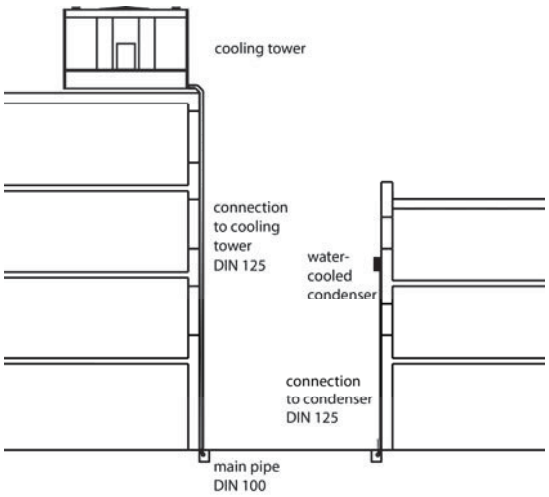


Figure 14: Section of backlane with technical elements.

Along the backlane, DIN 100 pipes on either side of the road serve as the main heat bus, installed in the covered rainwater trenches. Generic connection points allow to connect the decentralised condensing units to the heat bus with DIN 32 pipes. The cooling tower is connected to the main bus with DIN 125 pipes, crossing underneath the road to serve both sides of the road. The pump system may be set up as centralised where central pumps serve the entire network or as a hybrid where a main pump serves the main network and small decentralised pumps overcome the pressure difference for each unit separately, acting as active valves for each unit.

EVALUATION OF THE NEW SYSTEM

Methods to compare energy efficiency

The cooling demand for the row of shophouses was estimated based on currently installed cooling capacity. Most condensing units are visibly installed in the backlane, invisible ones and added volume from architectural intervention were added with 10% and 20% respectively. This led to an estimate of the total cooling demand of 700 kW. An estimation based on areas and specific cooling demand in W/m^2 yielded similar results, deemed good enough for the exploration of this system.

The calculation of fan and pumping power followed a simplified version of the methods outlined in [11]: instead of calculating continuous and local pressure drops, specific values in Pa/m were assumed, following the dimensioning of the pipes with engineering tables.

The same parameters as in [11] were used to calculate the chiller efficiency with equation (1) for 4 different scenarios. The evaporation temperature T_1 was 8ºC and the condensing temperature T_2 was 55ºC and 35ºC respectively. Scenarios 1 and 2 assume air-cooled air-conditioning with an internal exergetic efficiency of 0.4 and of 0.5 respectively. Scenarios 3 and 4 are the water-cooled solutions implementing this heat bus system with an exergetic efficiency of 0.4 and 0.6 respectively. The larger increase of the internal chiller efficiency can be postulated because of the more stable operation conditions from the centralised cooling tower. Because the water-cooled condenser never has to operate at 50+ºC, it can be optimised for smaller temperature lifts and can yield higher internal efficiencies. The performance of the system is measured in exergy demand [kW], which in this case is equivalent to electricity demand, and in COP of the whole system.

Comparison of energy efficiency

Figure 15 shows the exergy demand for each of the system setups, comparing air-cooled to water-cooled solutions. Increasing machine efficiency of the air-cooled solution alone decreases demand by 20%. Exergy demand for the heat bus system is reduced by 36% with standard exergetic efficiencies and by 56% with high-performing water-cooled condensing units. The system COPs for the different scenarios are 2.7 and 3.4 for the air-cooled systems and 4.2 and 6.1 for the heat bus systems.

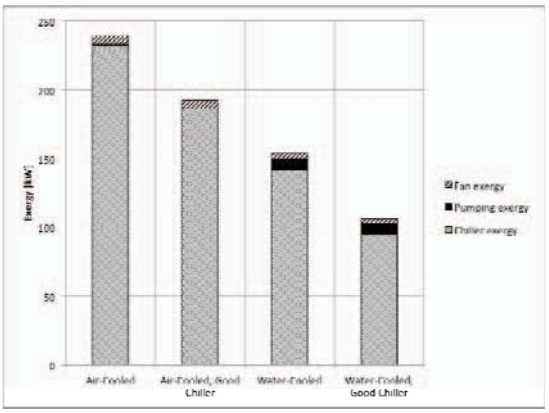


Figure 15: Comparison of standard air-cooled and water-cooled heat bus system.

The results hereby show that the exergy demand may be reduced by more than half, including the additional pumping power needed to move the water in the hydronic network. This does not even account for the potential of other improvements on the evaporation side where the cooling is supplied in the building, i.e. separation of sensible and latent loads or using dessicant dehumidification [12], but assumes that inside the buildings, cooling installations stay exactly as they are.

Increasing internal machine efficiency alone for air-cooled systems cannot improve the system efficiency as much as changing the system completely to evaporation driven heat rejection.

The non-chiller related exergy demand for the heat bus system is less than 5% of the air-cooled exergy demand. The majority of the exergy demand is thus still with the individual chillers and not the common infrastructure of cooling tower fan and pumps.

Scale of heat bus systems

The heat bus system has in this case been applied to this one backlane. It represents a prototypical evaluation for a heat rejection network in the horizontal direction, in a similar way as the study on the HDB building Treelodge [11] represents a prototypical evaluation in the vertical sense. These may be combined or extended in any kind of network typology, technically only limited by the minimum size of commercially available cooling towers, roughly 500kW heat rejection capacity. This network with 40 shop houses for 1 cooling tower is at the lower end of the scale. In principle no distinct upper limitations to the size of the network exist from a technical point of view. However, as the networks grow larger, the diameter of the main pipes will increase, rendering their installation into the existing fabric of buildings and roads more difficult.

Location of heat bus infrastuctures

The evaporation of water in the cooling tower leads to an increase of temperature and especially humidity in its vicinity and may lead to problems like increased growth of algae. This can be prevented by ensuring that the saturated air does not accumulate locally but is instead mixed with the surrounding air of lower humidity, and is carried away by wind. It is therefore advisable to place the cooling towers in high locations exposed to airflows, i.e. roofs, as it has been done in this design exploration or in the case of the study on high-rise building with 1 cooling tower for the entire network.

The pipes for the heat bus can be simple steel pipes, without any insulation material, installed preferably at the outside of buildings and not inside. The temperature between the water flowing inside and the outdoor air temperature is very small, resulting in negligible heat conduction. To prevent significant heating up from solar radiation, it is advisable to paint the pipes in reflective colours or installing them in shaded locations. At the street level, the main pipes may be placed inside the rainwater trenches (see Figure 14).

Public/ private ownership and operation

As with all shared infrastructures, the questions of who owns and of who operates the infrastructure are central considerations. In the case of the heat bus systems, there is clearly a shared infrastructure comprising of cooling tower, piping and pumps – infrastructure that needs to be built first and then continually operated. It is of course possible to have one entity that owns and operates all the equipment all the way to the indoor air-conditioning units. More appropriate is probably to have a separation between the shared infrastructure and the individual equipment, i.e. condenser and indoor units. Since a critical mass needs to be achieved before it makes sense to build a heat bus system, a coordinating organisation is necessary. The simplest situation is obviously if there is only one owner, as was the case for the China Square Central backlane project.

Possible organisations are administrative entities like the city or the state, professional energy service companies (ESCO), commercial or non-profit, and community driven entities like cooperatives. In all cases, the users would pay regular fees to cover capital and operation cost. An initial buy-in fee may be possible, like somebody buying an MRT card or joining a car sharing program.

Metering of the use of the infrastructure is necessary and easily possible with today's sensors to charge according to actual usage. A simple way might be to base the fees on electricity usage for air-conditioning and rated capacity, a more sophisticated way would measure mass flows (like standard water meters) and temperatures. It could also be a flat fee, comparable

to the 3-monthly air-conditioning cleaning service that everybody is obliged to have, considering that only 5% is attributed to non-chiller related exergy demand for the heat bus system

This shared infrastructure may also be used to initiate a participatory planning process where the occupiers of the shop houses discuss and re-evaluate the spatial qualities they desire. Synergetic and mutually competing utilisations such as restaurants, shops, waste disposal, delivery, storage and other functions may be discussed in an effort to upgrade the quality of the space, as neighbourliness is extended to small businesses.

Urban comfort – heat and noise

Thermal comfort does not only depend on the air temperature but on the mean radiant temperature, exposure to solar radiatino and air movement. More measurements and simulations are necessary to better understand thermal comfort in outdoor spaces, as indicated by Yang [6].

While the front arcade has for a long time been an integrated thermal design feature, the backlanes have yet to get discovered as temporate spaces that not only connect street grid in a very efficient manner but also offer possibilities for further social public spaces within an existing urban fabric.

While absolute improvements are difficult to judge, it is clear that the new system will improve thermal comfort through the absence of convective heat sources at human height. Urban design interventions such as the planting of trees will further reduce heat from solar radiation. These shaded areas will not only protect protect pedestrians from the sun but also reduce the heating up of the hard concrete surfaces, such as road and walls, preventing them from reradiating that heat to pedestrians. That the built environment has two permeable facades allows them to become more permeable making the area as a whole more permeable and walkable.

The noise from split type units has not been measured directly in the backlanes but can be classified as substantial, especially if the backlane should be used for stationary activities such as cafés, restaurants etc. As was found in this study on air-source heat pumps, the noise from condensing units is mostly attributed to the fan and not the compressor [13]. The compressor can be acoustically shielded much better than the fan. Replacing the fans necessary for air-cooled units with a water pump will decrease the noise impact substantially.

Pedestrian movement

This change on the infrastructure level of the area has inpact on the thermal comfort which has a large scale impact on the pedestrian movement in this area (see Figure 16). Increased pedestrian movement increases the economic potential of the backlanes and with it the economic viability to further change in backlanes. It opens up the backlanes as a secondary transportation path through the area and diviates the people away from busy roads and their inherent pollution to the sheltered backlanes.

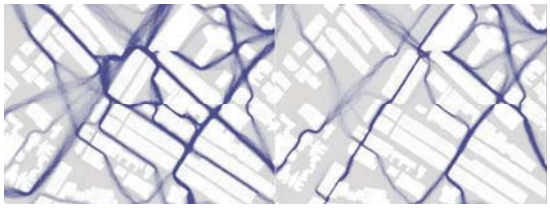


Figure 16: Simulated pedestrian movement, Left: existing configuration; Right: Improved thermal comfort

Cost considerations

The investment capital necessary to implement a transformation of the technical system has not yet been analysed. Investments will most certainly be larger than for the installation of air-cooled units – if only the technical systems are considered. Life-cycle cost will have to consider energy bills cut in half.

More interestingly however is if the technical transformation is combined with other upgrades to buildings and backlane. All measures combined will have impacts on multiple levels. Accessibility and permeability for pedestrians will create more economically usable spaces, will make now unused upper floors accessible, independent of the business downstairs. The upgrade will increase the urban quality of the neighbourhood and thus increase the retail value.

CONCLUSION

This study presents possible outcomes if we apply the LowEx design paradigm to a backlane in Singapore: We replaced the air-cooled condensers with water-cooled condensers, introduced a semi-centralised infrastructure, the *heat bus*, and combined that with architectural and urban design interventions.

The energy use for air-conditioning may be reduced by more than 50% compared to today's systems, combining the effects of more effective heat rejection and higher machine efficiency facilitated by stable operation conditions. Instead of rejecting heat directly into the backlane, blowing out hot air at body height, it is rejected centrally at roof height, removing heat and noise from air-conditioning, increasing thermal comfort for people using the backlane. This technological solution to reduce energy use raises question across disciplines and creates multiple benefits beyond energy efficiency, very importantly also regarding the increase of value of the existing building stock.

Changes to the volume of certain shop houses become interesting because they are suddenly accessible from the back, enabling the upper floors to be used differently, residential or commercial. Urban design interventions on a street level such as the planting of trees will further ameliorate thermal comfort and atmosphere, rendering the backlane into a (semi)public space that can be better used for pedestrians and for economic activities such as cafés, restaurants or shops.

The suggested design variation is a prototypical example of applying the *heat bus system* to a horizontal setting. Combined with the system evaluated for vertical high-rise solutions [11], this system may be applied to any kind of urban typology in the tropical climate.

This shared infrastructure is more flexible and modular than centralised cooling systems, chilled water systems at building scale or district cooling systems at urban scale, but can cut energy use for air-conditioning in half.

ACKNOWLEDGMENT

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INTRODUCING SUSTAINABILITY IN CONSTRUCTION SITES IN BRASIL: CHALLENGES AND OPPORTUNITIES

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ABSTRACT

Sustainability in Brazil is in its early days. In construction sites, where site management takes sustainability as an important priority, a column as central as cost, time and quality, middle management and the labor force fall in line, behind the objective. This paper departs from the perspective that there is an economic motive for pursuing sustainable practices. Given that a sustainable site has been contracted, one of two ways are preferred: (1) to have a team who will perform all related tasks while the others remain in their old ways or, (2) accept the idea that the construction way has changed and all must change. The main conclusion is that there is no choice between those ways, they are complementary and of an evolutionary process. One should start with a small and motivated team, who has a mission of educating and disseminating the new approach, not to do for the others.

INTRODUCTION

During the last decade, the Construction Sector in Brazil has expanded greatly due to favorable economic conditions, government programmes and big international events. This scenario has created great opportunities for absorption of sustainable technological paradigms, including the search for sustainable construction certifications such as the American certification LEED and the Brazilian certification AQUA.

Traditionally, in the construction process it has been considered, as competitive factors, cost, quality and time (CIB Report 237, 2000). By the size of the construction productive chain, the volume and quantity of materials apply, the very significant interference in the environment and the cost benefit of environment strategies, it has forced the traditional approach to search for new paradigms, considering environmental factors are also relevant.

The industry that produces buildings or engineering works is also considered the main chain, which the final product makes up the built environment: residential buildings, hospitals, schools, districts, avenues, bridges, dams, among others. The production process of these buildings varies between being highly sophisticated or using traditional processes, which impact the environment and always alter and affect drastically the landscape, affecting the ambience.

The impacts caused by the construction process include resource consumption and environmental loads caused mainly by the indiscriminate use of energy, natural resources, emissions of CO_2, pollutants, and waste generation.

Statistics show that in urban centers with more than 500.000 inhabitants construction processes are responsible for 40% to 70% of the volume of solid urban waste (Blumenschein, 2004). In the Federal District (Brazil), it is estimated that between 20% and 50% of this total are disposed irregularly, causing a great impact on the environment and society.

The disposal of these residues in valleys, edge of streams, vacant urban areas and unpaved streets tends to cause great damage to urban drainage and public budgets. In Brazil, in urban areas with populations over one million inhabitants, it takes around $ 300,000.00 (three hundred thousand dollars) per month to reap construction waste which have been deposited underhand, as confirmed by the few reports of Brazilian municipalities (Comurg, 2001).

Much of the built environment has been produced through a technological path based on capitalist economic logic, consolidated in the last two hundred years, which has assumed "that nature is a means of producing wealth" (Bursztyn, 1995:100). There is still an utilitarian rationality, based on a paradigm that justifies to explore nature without thinking ahead.

It has been learnt and exercised the combination of production factors without worrying about the future and the costs of using nature, either exploring natural resources, including the use of space for buildings in the built environment, or generating waste and pollutants which arise from this process.

The purpose of introducing and accelerating the paradigm shift in the construction industry requires the development of methodologies which aim in building effective networks. The networks must be structured in order to allow that knowledge, information and technology are generated and applied in a synergic scenario integrating agents and actions in conjunction with instruments (command, legal, technical, educational and economic), which in

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turn will enhance changing values and strategies, allowing the consolidation of a technological path concerned in maintaining the balance of the environment.

Strengthening learning systems, focused on sustainable construction, is indispensable for the consolidation of a continuous learning in a sustainable way to produce the built environment.

The continuous monitoring and evaluation of the results allow modifications necessary to achieve concrete results.

The principles of innovation and systems theory stress the importance of the systems of learning organisations (Blumenschein, 2004).

Johnson (2010) offers an approach that emphasises the complexity of vectors interconnection that influences the emergence of innovations, and in his coral bank analogy it is confirmed the importance of collaborative networks.

From this perspective, the survivability of coral reefs, is not a result of the ability of survival of the fittest, but the ability to reinvent solutions from the results of exchanges and interactions that allow the discovery of new ways of survival. This is the definitive explanation of the paradox of Darwin: "The coral reefs found many ways of survival because of the way they share" (Johnson 2010:245).

By applying this analogy to the context of learning organisations the sharing, integration and interconnection of resources, expertise and responsibilities can be considered as a major factor in the process of paradigm shift.

SIMULATION

"The whole is a sum of its parts". From a site management perspective this parts could be: engineering; supply, planning, and construction. Sustainability became an important issue; fine, this reasoning would direct us to create a new part to be added to the Site Management Chart – a Sustainability Team. The new Team will take care of the sustainability issues. Within this category we still could discuss the new part's position on the Chart; further up or down, and so on.

This has been the main approach chosen by firms within the construction sector in Brazil. This choice means that it will have a team in charge of doing the sustainability tasks, for everyone else on site. Be it intelligence (thinking about) or effective actions on the field, the kind one account for. This strategy's probable future is that with time, the new team is seen as essentially a new category of cost, imposed onto the contractor.

This paper believes that the strategy laid down above is not enough to get the job done. Lacks integration and one has to do more, in other words - "the whole has to be greater than a sum of its parts".

Thus, having as a main fundament that it is through integration and interconnection of agents, instruments and actions in the construction process, sharing responsibilities, expertise and resources that it is possible to achieve changes towards sustainability, the Scom Ltd. has developed its methodology, presented in Figure 1.

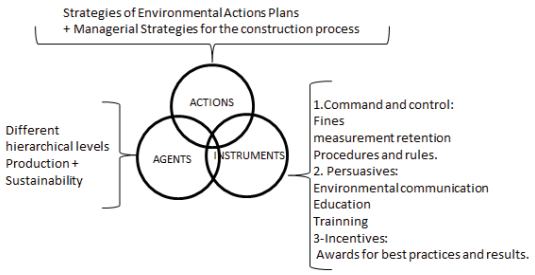


Figure 1: Scom metodology

In this paper, the system proposed by Scom Construction, Projects and Consultancy Ltda., which is based in Brasília, Brazil, since 2005 is used as a framework for the proposed analysis.

The Scom System was developed aiming to support construction companies (Developers and Contractors) in the process of obtaining environmental and sustainable construction certifications such us LEED, BREEAM, AQUA, ISO 14000, among others.

It is through the use of managerial learning technologies and positive critical learning that it can be assured that a paradigm of sustainable construction is absorbed in the construction process, ensuring compliance with the requirements of the applied certification.

Accordingly, the Scom System implementation method involves the following steps:

- Diagnosis – Identify and qualify how the Company works from a managerial point of view;
- Planning – Define objectives and preparation of Sustainable Action Plans (SAP);
- Planning – Establish strategy to implement each SAP;

- Implementation – Preparation of the teams responsible for production and sustainability with presentation of the SAPs, its strategies, evidence required and indicators;

- Implementation – Execution of integrated plans;

- Monitoring – the integration of the production and sustainability teams and the attendance of the certification criteria; when necessary adjustments are introduced;

- Managerial Forum – Meeting as a tool, in which participate the agents responsible for the site management, designed to analise and correct trajectory at a strategic level, happens every 30 to 60 days;

- Foremen Forum – Meeting in which participate the agents responsible for the service fronts, and has the objective of discussing at a tactical level strategies and procedures focusing sustainability, happens every 15 days;

- Educational and training program – in order to prepare collaborators and establish desired standards;

- Communication – Implementation of report and internal communication program, as a way of assuring that all hierarchical levels are aware of the results achieved during the process.

The monitoring system is composed of check lists organised in spreadsheets which have focus on raising information in order to assess the level of integration beteween agents, actions and instrumetns, as well as the criteria of certification process.

Table 1: Scom system

Implementation of a System to facilitate Sustainable Construction Certification	
MONITORED ITEM	NUMBER OF CRITERIA IN THE MONITORING PROCESS
1. Diagnosis of the Company's Operation System	
Implanted systems	04
Environmental and Social Responsibility Program	03
Installed competence	06
2. Planning	
Preparation of Sustainable Action Plan	06
Schedule	02
Construction Site Project	02
Definition of staff responsible for certification	02
3. Implementation of the SAP	
Diagnosis	03
Monitoring	03
Communication	02
SUSTAINABLE ACTION PLANS	
Waste Management Plan	
The site preparation	10
Waste segregation	04
Storage	03
Waste gathering and destination	04
Cleanness and organisation of the front services	03
Environmental Education Plan	
Implementation and training	07
Awareness	02
Communication	04
Registers and monitoring	01
Prevention and Environmental Control Plan (According to strategies defined for each certification. It includes 44 criteria)	
Air quality plan (It includes 22 criteria)	

The main tools which allow the absorption of managerial learning technologies and positive critical learning are the strategies that aim to integration and interconnection of agents, actions and instruments such as: managerial forum, foremen forum, educational and training program, and communication.

Through the forums standards misunderstanding, mistakes and lack of communication are corrected and pursued results are internalised. The educational program strengthens the learning systems assuring the absorption of the required solutions and strategies. The communication program inform the whole team of failures, results and necessary changes, working as an instrument of incentive as well as capacitation.

ANALYSIS

The system presented above has been used to advise construction companies in the sustainable construction process.

In this paper, three experiences in the central part of Brasil shall be looked at considering: the percentage of the Scom system criteria attended during the construction process; the appointment of a

sustainability team and the level of integration of sustainability and production team on site.

Table 2: Brazilian Sites and the implementationof Scom metodology

SITE A	
- Office Building - Built Area - 155.000 m^2 - Consortium of Construction Companies contracted for the construction process - The certification aim was silver and before the ending of the process it was upgraded to gold.	
Percentage of the Scom system criteria attended during the construction process	More than 100% of the criteria defined by the Scom System have been met.
Appointment of Sustainability Team	
Since the beginning of the process it was appointed a specific team responsible for the coordination of the sustainable construction certification process. The coordinator had assistance in the administrative tasks as well as on site. The team on site was around 30 professionals trained for cleaning, waste management and prevention and control of environment impacts. Although the command of the site has been under the production team.	
Integration sustainability team and production team.	
During the first six months various meetings were held in order to make clear the importance of the integration of sustainability and production team. The managerial and foremen forums were systematically implemented as well as a strong educational program which was amplified in order to include quality, security and health standards, besides de prevention and control of environment impacts. The integration of sustainability and production team were complete to a point where in order to approve the finalisation of services both should sign, aiming to assure that environmental strategies were accomplished.	
SITE B	
Office Building - Built Area – 155.000 m^2 Construction Company partner in the Development	
Percentage of the Scom system criteria attended during the construction process	55% of the criteria have been met
Appointment of Sustainability Team	
Since the beginning of the process it was appointed a specific professional responsible for the coordinating the certification process in the construction process, among other functions. Few collaborators were attached to the coordinator once problems in the attendance of the certification arose. The team responsible for the production process had the complete command of the site.	
Integration sustainability team and production team.	
The production team has treated sustainable strategies as a responsibility of the certification coordinator. The managerial and foremen forum and the educational sustainable plan have never been implemented accordingly to the Scom methodology. The integration between sustainability and production teams did not happen and the process of certification was very stressful. Few criteria of the certification were not attended.	
SITE C	
Public Building - Built Area - 188.000 m^2 Consortium of Construction Companies	
Percentage of the Scom system criteria attended during the construction process	80% of the criteria have been met.
Appointment of Sustainability Team	
At the beginning of the process the responsibility for the site certification process was much diffused. After the first problems for attending the certification criteria arose a specific team was appointed.	
Integration sustainability team and production team.	
In order to ensure the integration of sustainability and production teams it was necessary introduce capacitation strategies and make the managerial team ware of the importance of this integration. Once the managerial team understood that it is through this integration that effective results can be achieved the attendance of the certification criteria became a fact.	

It should be emphasised that, when it was possible, the complete integration of production and sustainability teams, the process of attending certification criteria was much more effective and smooth.

It is necessary to point out that this integration is a relevant indicator in the process because it reveals

that sustainability is not external to the production, but an integral part thereof.

Among the main drivers which work for the effectiveness of attending sustainable criteria on sites it can be mentioned:

- The importance of considering, when planning the construction process, the time required for preparation of necessary infrastructure to meet the strategies of Sustainable Action Plans, such us waste deposit areas and clean vehicle wheels, among others.

- The assessment, along the construction process, of the adequacy of teams responsible for meeting Sustainable Action Plans strategies, attending the required certification.

- The definition of organised teams with specific functions, which are structured to meet the strategies established by the Sustainable Action Plans. When functions are not well defined and the organisation of the team responsible for the sustainability on site is confused there is no effective attendance of sustainable criteria.

- The integration of the teams responsible for the management and production decision-making and delivery of services to the site sustainable strategy in order to assure attendance to sustainability.

- Strengthening the command line throughout the process to ensure compliance with the strategies of the Sustainable Action Plans.

- The importance of recording what happens on site allowing to follow the history and track results. The presence and monitoring by daily work is an important strategy.

- The importance of the Environmental Education Plan, with a focus on awareness strategies and training in order to prepare the workforce.

- The importance of implementing training program for engineers to strengthening the process of care for Sustainable Action Plans.

- The work late and the requirements of service strategies for LEED difficult care strategies of the Environmental Action Plans.

- The assessment of the construction system considering the potential for generating waste or complicating the attendance of sustainable criteria.

- The production team should be integrated to meet the strategies of the Action Plans, Sustainable effectively since the beginning of the work.

- Communication problems with the warehouse.

- Management of the project information on site avoiding old .

CONCLUSION

There are big challenges in the process of introducing strategies which minimise and control environmental impacts in construction sites. Among the aspects which work against successful results is the culture of engineers and labor force, management inconsistency and lack of integration and interconnection among production and sustainability teams in the construction process.

This article has presented few lessons which can lead to effective results when applying for a construction certification using as reference few experiences in Brazil.

The main factor to be pursued is the complete and synergic integration of agents in construction sites (different hierarchical levels in construction and environmental teams), their actions (strategies for Environmental Actions Plans and management of the construction process) and instruments (measurement of results, procedures and rules, use of information and educational strategies, penalties as well as incentives).

There are also great opportunities in this process as learning systems need to be strengthen and once a strategy is learnt new ways are developed which allow the absorption of new paradigms and the creation of solutions departing from different points of view which in term can be diffused.

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USE-END INFORMATION AS RESOURCE FOR WELL-TEMPERED DEVELOPMENT

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ABSTRACT

In order to better understand the operational parameters of the localised built environment and to deliver well-integrated services, it is considered necessary to manage use-end, or demand-end information. Use-end information can become key to the establishment of specificities of localised environments and projects, where the efficacy of given technologies or policies are tested. Regardless of the recently increased popularity of building monitoring technologies or information visualisation methodologies, many of the project-based tests have not played a role in presenting a systematic framework to manage the use-end information as a component within the comprehensive building information. To gain a clearer perspective on the characteristic of use-end information in various practices, this paper utilises a descriptive framework to systematically analyse the variance in the role of use-end *information as an agency* within the given projects. The paper aims to position the use-end information as a resource to projects where mining, aggregating and applying use-end information allow further value capture and value production. Through the case studies, the paper indicates current problems in the definition of use-end information as well as problems in the interface of information, where the potential for further value capture has been buried.

INTRODUCTION

The discourse of use-end/demand-based information has been shifting rapidly. As a result of the rise of interest toward the role of social networks and individuated information (World Economic Forum 2012), the overall resolution of information regarding the use and operation of building seems to gain specificity compared with those supplied in the past. It is not only at the agent level that information resolution is shifting; with the improvement of monitoring and analysis methodologies, the operational phase of the built environment has steadily become a domain of continuous and heuristic optimisation in parallel to the implementation of simulated assumptions (Sako et al. 2011). In these contexts as well, the data of the use-end becomes a significant factor to be monitored as a parameter for the optimisation of built environment. However, use-end information has been primarily discussed within and limited to the binary relationship of top-down and bottom-up approaches to problem solving. For example, the user-participatory approaches to project development was discussed throughout the 1970s as methodologies by Alexander in *Pattern Language* (Alexander et al. 1977) or Halprin in *Taking Part* (Halprin & Burns 1974). Earlier in the decade, however, Sommer already indicated the difficulty of transferring use-end information to design-based information, where he proposed the role of an interface agent for effective information flow among stakeholders (Sommer 1971). The discourse of information interfaces was developed mainly in the 1980s within the computer-to-human interface discourse, which studied the use-end as a necessary subject of incorporation to the design of interfaces (Hooper 1986; Norman & Draper 1986). User participation was again discussed in the 1990s in the context of user innovation (Hippel 2005), and further in the discourse of agile software development (Beck et al. 2001) in the 2000s. It is only recently that ethnographical approaches entered into the domain of design so as to integrate the use-end information within design processes (Brown & Wyatt 2010).

Regardless of these studies and their identification of the significance of agents for use-end information, the positioning of use-end information itself within the product/service life cycle has not been discussed clearly. In aiming to apply the discussed logics of use-end information to the building sector and its project (building life-cycle) information configuration, a great amount of barriers can be found due to the complexity of building projects. In order to analyse the capability of use-end information independent from the role of agents within the projects, this paper identifies the characteristics of information through information configuration perspectives. The paper utilises the descriptive framework to examine eight examples under four categories to distinguish the informational characteristics of use-end information within different approaches of use-end information engagement.

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METHODOLOGY

In 2011, a 70-household data survey was conducted, wherein the living environment of 30 households was monitored. The interdependencies of design-based information to the monitored operational data to agent-based information were analysed as indicated in Figure 1 (Morishita et al. 2011). Through the study, the necessity to consider the relationship of agent-based information and process-based information of the building within the same framework of building information was identified.

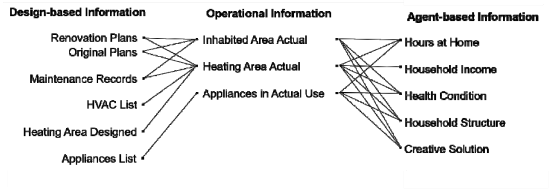


Figure 1: Information interdependencies in residential architecture, modified from Morishita et al. 2011

The earlier stated literatures associated with the agent-based perspectives on use-end information often did not consider the process-based applicability of their methodologies or approaches. For instance, Alexander's user participation process was considered applicable throughout the life-cycle of building projects (Alexander 1975), however it often failed to manage in the construction and operational phases due to the complexity of stakeholder relationships. Agile software development and its iterative design process is often argued as an alternative to traditional waterfall processes (Royce 1970), while in application to the discipline of architecture, it is more likely described by the combination of the two. In order to examine both the process-based and agency-based information, this paper utilises the 9-grid descriptive framework (Figure 2). The 9-grid descriptive framework is an information description framework, where agency and process axes establish 9 information domains for the effective clarification of information relationships, focus specifically on the role of the information interface between the supply-end and the use-end of built environment (Morishita 2013). Through partial application of the 9-grid descriptive framework to various contemporary cases of use-end information engagement, the paper aims to clarify the exact role of use-end information within the overall configuration of building information. For the purpose of analysis, only one section of the process axes is used for each example. The object-based description of the given example is shown to the right of the 9-grid description to clarify each example.

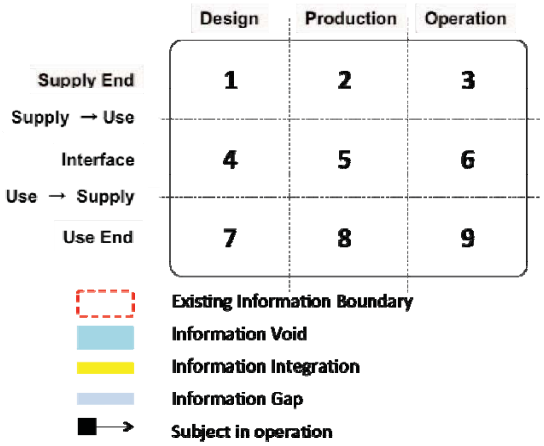


Figure 2: The 9-grid descriptive framework

CASE STUDIES

Table 1 lists various approaches that aim to acquire use-end information for different purposes.

Table 1: Approaches to the use-end information

APPROACHES
1: Supply-end lead approaches
a: Ethnographic Survey for Design
b: After-sale Service
2: Operational Management-based approaches
c: Smart Meter
d: Data Aggregator
e: HEMS/BEMS
3: Use-end agent-based approaches
f: Life Log
g: Internet Forum
4: Policy-based approaches
h: Home Information Record System
i: GHG Emission Measurement Standard

These examples were chosen as a case study of the information domains associated with the use-end and operational phase within the 9-grid framework, which has recently gained major significance in the building industry. The parameter of the cases was set in four categories, starting with supply-end engagement toward acquiring use-end information, followed by a focus on interface agencies that utilise use-end information during the operational phase of built environment. These two cases represent supply-oriented approaches. The third group shows the use-end-based incentives for producing use-end information. The forth group shows policy-based approaches, where the agencies are acting as an interface for the use-end information and the supply-end objectives. The focus of the case studies is in the location of information production, the distinction of

information interfaces, and in the gaps and voids of information resulting from specific information configuration of given approaches. An emphasis is given to the gaps and voids of information within the 9-grid to visually communicate the difference amongst the approaches.

CASE 1: SUPPLY-END APPROACHES

The paper first takes the cases of supply-end lead approaches to use-end information, where the recently popularity-gaining ethnographic survey approach in the design process and traditional after-sale service approach is considered.

Ethnographic Survey

The Ethnographic Survey approach to design practice has been used within the discipline of architecture for a prolonged time. However, recent efforts from other design fields have included policy-based, economic, or social dimensions to their informational parameters by mobilising a disciplinary specialist as part of the organisational capability for design projects, enabling those parameters as the subject of management (Brown & Wyatt 2010; McCreary 2010). This approach has shown its effectiveness in project implementation in developing countries as well as in the industrial design domain, providing various solutions to environmental problems. Surveys are often executed as problem recognition and definition processes, not as archival processes. The interface agency produces the information for the use-end through the surveys; the survey functions as a technique for the use-end to produce information. Through its multi-stakeholder-based interdisciplinary approaches, the information production at the use-end environment integrates various parameters, while the design-end agencies also go through iterative processes to integrate further information with their prototypes for a solution (Figure 3).

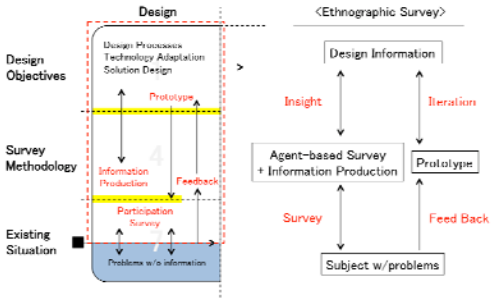


Figure 3: Ethnographic survey of the use-end

Since this approach is often presented in the form of design consultancy, contractual parameters present the boundary of iterative processes of problem definition and implementation. The 9-grid framework makes the role of interface agencies apparent, along with their role in aggregating the use-end information. While information production by the use-end agents is not a prerequisite, there are much potential to be incorporated as the methodologies evolve.

After-Sale Service

In the typical after-sale service model for building products (Figure 4), it is still prominent that product delivery marks the end of the service boundary, where models of product-service-system (UNEP-DTIE SCP Branch 2002; Tukker 2004) or service-oriented business model to incorporate use-end and operational information is not commonly employed. Often the call centre is located as the agent for the mitigation of problems or risks that emerge at the use-end. With the compiled information on the product/service in the operation phase, it is considered difficult to identify the specificities of environmental information behind each problem and its parameters. Therefore, in the 9-grid description, the void of information at the environment level is identified, while individual cases of operation and the problem may be acquired. In the case study of a sanitary-ware company in Japan, the technical centre agents were assuming the role of interface agent for the environment-based information through the on-site visual surveys. However the distance between the actual end-user and environmental parameters is still a problem to be considered for a more effective feedback system (Morishita et al. 2012).

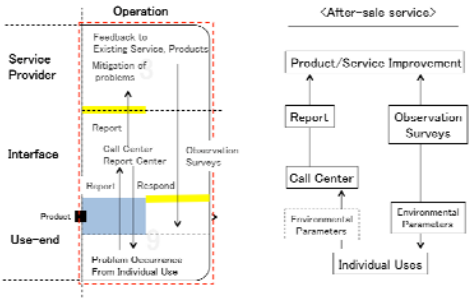


Figure 4: Common after-sale service

From the two cases of use-end information engagement by the supply-oriented approaches, the 9-grid clarified the role of interface agents and the difference in the characteristics of information previously considered under the blanket of *user* information. This perspective on the information configuration, serve to point out the necessity to redefine the disciplinarily ambiguous term *user*, where their configuration of information can be further characterised by distinguishing the environment and agent dependent parameters.

CASE 2: OPERATIONAL MANAGEMENT-BASED APPROACHES

The role of use-end information in energy-related management of the building industry is often considered as demand-side management. Recent interest in the introduction of renewable energy to the existing energy grid heightened the interest in methods of acquiring demand-end information for the improved management of supply-demand balancing. Since there are many approaches to the management of demand-end parameters, it is difficult for various non-specialised stakeholders to understand the difference amongst these managerial approaches.

The 9-grid description aims to clarify the difference by indicating the characteristics of information integration amongst these methodologies. The first example compares the information penetration level of the supply-end of electricity, which aims to reduce the overall energy consumption by reporting the measured result to the use-end. In particular, the example of the use of smart meters provided by an electric company is compared to the example of the data aggregator model. The example of the data aggregator model was referenced from an existing business model (Goldstein et al. 2008; Allcott 2011) with abstraction of certain details of operations for the purpose of the comparison.

Smart Meter

The installation of a smart meter by the electric company often provides the use-end with a visualisation of their energy consumption patterns. The supply-end gathers data for demand prediction, while the use-end is expected to reduce their energy consumption by way of self-engagement based individuated, visualised information. As indicated in the 9-grid (Figure 5), the degrees of reduction at the use-end are dependent on the use-end, while the main aim of the supply-end remains in supply/demand balancing. In this sense, the smart meter is a supply-end information interface, where use-end information is produced within the supply-end logic, often omitting use-end information such as individual household data.

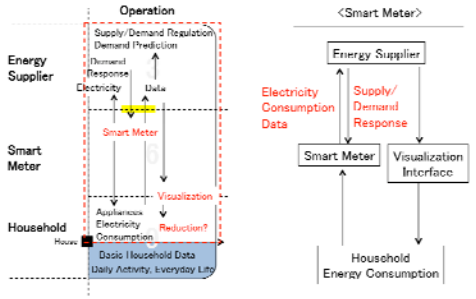


Figure 5: Smart meter

Data Aggregator

In comparison, the case of the data aggregator model shows engagement with the basic household data. The model exemplified here shows the aggregation of data from the electric company and the household data, which enables a detailed analysis of mass data to position individual consumption patterns within the relative consumption of a given group (Figure 6). The engagement with the use-end data enables the use-end agents to establish a better incentive toward reduction of energy consumption. The 9-grid marks such difference by the penetration level, where the latter is acquiring deep information from the use-end, while the former focus on the supply-end management issues.

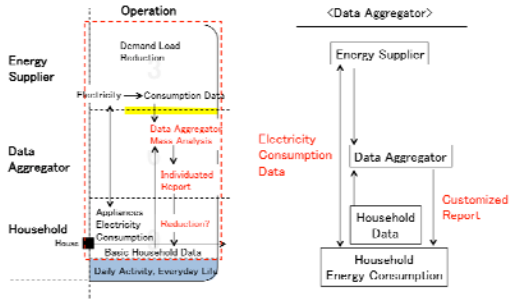


Figure 6: Data aggregator

HEMS/BEMS

Building Energy Management System (BEMS) is used by facility managers or the building owners to better manage the use of energy throughout the operational phase of the building. This is not only limited to large scale buildings, but has also become highly popular in residential applications, where Home Energy Management Systems (HEMS) are installed. Regardless of their popularity, various practices in the industry often define the term management in alignment with their own purpose. Some systems have building monitoring and environment controlling capabilities, while others simply act as an energy consumption visualisation tool. Since the majority of residents or building managers are not equipped with specialised knowledge on building equipment or HVAC system configuration, the role of visualisation is not directly associated with the optimisation of building operation. In this regard, it is important for the building owners to be equipped with knowledge to make distinctions between the different functions of HEMS/BEMS, in order to develop their awareness of the service level within the contracts. Figure 7 shows HEMS/BEMS with and without the controllability of building equipment. In the case of system instalment without controllability, it is likely that the optimisation of the building operation must be contracted to sub-service provider with the

information produced by the system. From the contractual perspective, this case is understood as a form of product provision rather than service provision. In the case of HEMS/BEMS with controllability, the system engages with the operational data to act upon HVAC optimisation (Sako et al. 2011). The installation of the management system is considered a part of HVAC management service provision. The provision of controllability most likely includes the detailed survey and analysis of building configuration and use-end requirements, engaging further with the operational parameters of an individuated use-end.

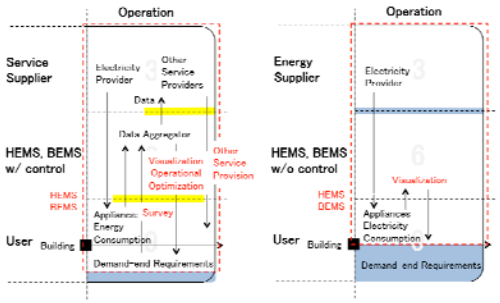


Figure 7: HEMS, BEMS

Through four examples of managing the information of use-end energy consumption, the 9-grid description clarified the difference in penetration levels and their associated capabilities in controlling and optimising the operation of building equipment. In many discussions on smart cities or sustainable development, the installation of systems or equipment is often discussed without the implications of their operational capabilities. The 9-grid suggests the necessity for the unambiguous communication of systematic capabilities of each system within the procurement processes.

CASE 3: USE-END APPROACHES

The case of use-end approaches explores the difference between the characteristics of information produced by the use-end and the use-end information produced by the supply-end/interface agencies. Earlier examples of use-end information produced by the supply-end/interface approaches indicate that they always leave voids of information at the lower-end of the 9-grid where the use-end information remains in the form of interpretative or analytical data. In order to further clarify the difference, this case displays the use-end information produced by the use-end. In the examples of Internet forum and life log, much of the incentives for information production are on the use-end. Such classification of information is often called *user-generated content*, however, in order not to confuse the term *user*, the paper uses rather generic classifications of use-end information, where the information is not necessarily dependent on the agent being the *user* of the given product or service.

Internet Forum

The first case follows the case of Internet forum, where use-end information is generated through the interest of the use-end toward a product/service (Figure 8). The information flow is not always bi-directional. Some users only upload information, some only read information, some engage in developing the thread or in the facilitation of collected information. With enough content, a certain degree of knowledge is expected to be accumulated with regard to specific issues. Since the use-end agents also explore the format of discussion, complex and specialised information (such as the contextual information of building technology) is less likely to be documented in product/technology-based discussions. Regardless of information resolution, these forums have been indicated as a place of user participation toward the innovation of given building technologies (Hyysalo et al. 2013). Some future discussions may be found in the interface between the collected, potentially resourceful information and the utilisation of such information by the supply-end for better feedback on their product/service operation.

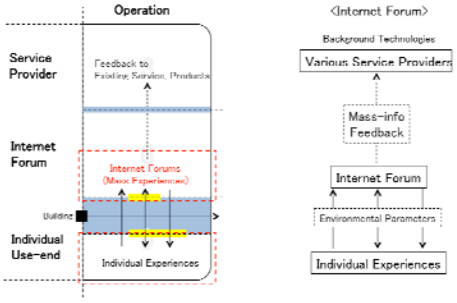


Figure 8: Internet forum

Life Log

With the risen popularity of smart phones or similar net-enabled portable computing devices, the ease of recording, documenting and presenting one's personal data has contributed to the rise of personal information production, which is collectively known as a life log as shown in Figure 9 (Bell & Gemmell 2007). Similar to the Internet forum, a life log enables information at an individual level. However, the environmental parameters that are associated with buildings in particular are often omitted from the information production, where the void in the information domain can be seen.

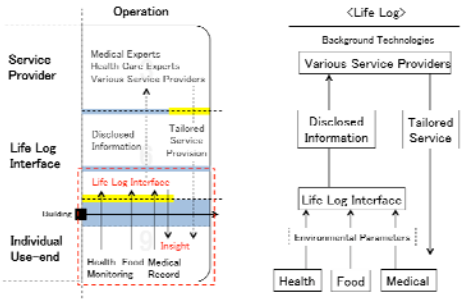


Figure 9: Life log

These two examples indicate that even though the technological and incentive parameters for the production of use-end information are viable domain of information, its association with the supply-end is still unclear. Specifically, the relation of use-end information to the non-product-based environment related information of architecture has yet to be clarified.

CASE 4: POLICY-BASED APPROACHES

The forth case examines use-end information in relation to a policy-oriented information system and an information production standard. The first example with the information system explores the role of use-end agent as the owner of information associated with housing. The second example with the Common Carbon Metric (CCM) explores the role of measurement/report/verification (MRV) boundary definition as communication interface for use-end diversities.

Home Information Record System

The Home Information Record System as shown in Figure 10 considers the equality in the ownership of information, where the third party agency assists the homeowner in their ownership and management of residential information throughout the life cycle of building. It is considered as a *user-oriented information system* for residential buildings (Aikawa 2004). Stocked information is not limited to the design and construction documents; information system manages maintenance and renovation documents; appliance related information; energy usage; and HEMS related information. The expected outcome of this system is to resolve the current asymmetry of information in the used housing market in Japan. Currently, in its early propagation stage, an exemplary third-party information system agency manages the information of 20,000 households in the system, where roughly 10% of the homeowners have registered to activate the user-end information system. In the future, it is expected that owners themselves will be involved in the production and recording of information associated with their daily lives, however at the current stage, most of the information is produced and recorded by supply-end contractors. Since it has become a requirement to maintain a home information record to apply for subsidies toward long-life quality housing, the incentive toward the production of information is currently policy-oriented. In the 9-grid description, the information at the use-end is nearly a void at this stage, whereas the lack of incentives or interface for information production results in less involvement from the use-end. In this case, the term *user-oriented information system* is understood as an indication of property of information at this point. For the system to function as *user-engaged system*, it will need another layer of systematic configuration in the interface domain.

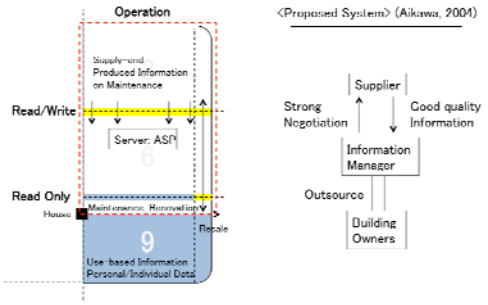


Figure 10: Home information record system

Common Carbon Metric

Since the operational phase of building has gained much attention in the discussion of reducing green house gas emission, MRV incentives have been developed in many sectors. However, the use-end of the building has diverse objectives in their operation of buildings, resulting in various measurement protocols and units of measurement that often favour individually set parameters of reporting. Such localised diversity cannot be avoided. However the incomparability introduces barriers in establishing a global policy or communicative reporting system. Common Carbon Metric (CCM) as shown in Figure 11, is an example in establishing a communicable MRV standard (UNEP-SBCI 2010). CCM aims to standardise the boundary definition of MRV, where individuated differences in the actual configuration of consumption is not questioned, acquiring only the annual total GHG emission of the establishment. In the 9-grid description, it is possible to visualise the boundary definition as not penetrating the individual configuration of building systems, yet establishing a communicable measurement. In this sense, it is a parameter tool for GHG emission issues, and is neither a model nor regulation for reducing GHG emission. Articulating such difference is significant for the propagation of policy or standards and building industry is expected to take a significant part in Emission Trading.

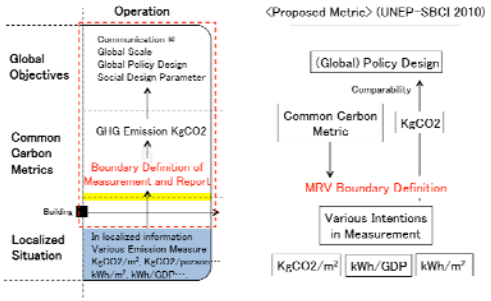


Figure 11: Common Carbon Metric

These two policy-oriented approaches described in the 9-grid shows that in top-down approaches, information production does not necessarily takes place at the top-end, where the interfacing parameters enable informational diversity or information ownership at the use-end information domain. In both cases, the information is integrated at one end of interface domain, where such differentiation can lead to the recognition of necessary improvements in the information systems or standards.

CONCLUSION

The paper exhibited that the terms associated with operational phase of building and its agency can become vague within the actual complexity of the projects and building operations. These domains of information production were clarified through 8 examples using the 9-grid descriptive framework, which analysed the information penetration level and difference in the characteristic of interface on both the supply-end and use-end.

The study clarified the differences among *user*, *demand* or *customer*, where the difference is exhibited as variations in information configuration, instead of as terminological definition. It is expected that further case studies within each example will be conducted, where the resulting visualisation can be utilised for communication amongst stakeholders of projects.

The study also showed that regardless of the risen popularity of data production on the individual and personal level, the use-end information production interface in the building industry is currently still limited. The further involvement of industry to engage the development and application of use-end information is expected in the future.

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FINE TUNING OF BUILDING SERVICES BY ANALYSING OF AND VERIFICATION WITH DATA COLLECTED FROM BUILDING AUTOMATION SYSTEM AND OCCUPANCY SURVEY FOR ST DIAMOND BUILDING

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ABSTRACT

A Building Automation System (BAS) controls, monitors and coordinates the technical services in a building. It can also be utilised to manage and improve the energy efficiency and reduce operating cost but it is usually not exploited. Improvement of building energy efficiency by using BAS is technically the simplest way, with a systematic 4-step optimising method. For example, areas of improvement were easily indentified and optimised; resulting in 42.8% cost saving from reduction of peak load demand with certain condition and 13.3% of energy saving from increment of lighting set point in ST Diamond building.

Industrial standards used for energy efficient design such as MS 1525 are conservative and set the lowest bar for code compliance. It is demonstrated in this study that visual comfort is maintained even with lower illuminance level.

INTRODUCTION

BAS is widely used in buildings but the full potential is often not explored. BAS can be equipped with function to measure energy usage of the building services. It is important to measure the energy consumption of a building in order to improve the energy performance. Besides, BAS is equipped with measuring function but the data is not utilised. By analysing these data carefully, the fine-tuning possibility can often be found easily.

Apart from that, the design of building systems are often considered sufficient when complying with the standards such as MS 1525:2007 and ASHRAE standards. However, these standards together with "common practice" in Malaysia are considered conservative and are intended for the worst-case scenario. By having the real-time data of the building system from BAS together with occupant surveys, the settings of the building systems can be adjusted to a more stringent level, to accommodate the real needs of the occupants.

The first objective of this research is to demonstrate that increasing energy efficiency and reducing operating cost of a building can be achieved by a simple method with minimal cost, which is by utilising the BAS. The second objective is to demonstrate that opportunities for optimisation can always be found with the help of BAS, even in already highly efficient buildings. The third objective is to find out the more stringent set point comparing to standards, with the aid of BAS, in order to increase the energy efficiency and comfort level of an office building.

The first hypothesis is that the fine-tuning possibility of an energy efficient building (ST Diamond building) can be discovered by analysing the BAS data, and consequently making changes to the set points of building services such as air conditioning and mechanical ventilation (ACMV) system, to improve energy efficiency and reduce operating cost of the building. The second hypothesis is that the efficiency and visual comfort in ST Diamond building is not compromised with a more stringent illuminance set point compared to MS 1525:2007.

THEORY

Building Automation System

BAS offers effective control of building services including ventilating, cooling and lighting appliances etc., which lead to building energy efficiency and improve operational of building. In order to avoid unnecessary energy usage and CO_2 emissions, integrated energy saving functions and routines can be programmed in the BAS based on the actual consumption of a building, depending on the end user's needs. BAS is providing essential information for the purpose of energy management such as operation schedule, energy usage and system status via data logging. These data are used for monitoring, documentation, controlling and optimising, in order to improve energy performance of buildings (CEN, 2011).

Saving Strategy with BAS

According to various sources, average energy saving percentage of a building with BAS system comparing to a building without BAS ranges from 5% to 31%. (Brambly et al., 2005) (as cited in ABB, 2009). According to ASHRAE, BAS can aid in saving more

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than 14% in annual cost in term of lost productivity of the building occupants. (as cited in Yin, 2010) Besides, according to a study in Germany, BAS components are contributing to energy savings in lighting control (25 to 58%), ventilation control (20 to 45%), room heating control (14 to 25%), shutter control (9 to 32%) and heating automation (7 to 17%) (as cited in ABB, 2009).

However, installation of BAS alone does not ensure energy saving in reality. According to a study in New England, five out of 11 BAS equipped buildings save 55% less energy than anticipated (Kamm, 2007). Therefore, the installed BAS needs consistent fine-tuning to achieve the desired savings. Unfortunately, this is often being overlooked. It is the fastest, technically simplest and required least investment, which will give great savings in return (Trend, n.d.).

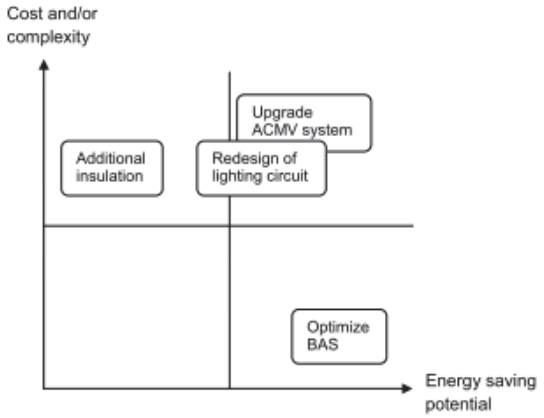


Figure 1: Comparison of different saving methods

Some common strategies and best practices can be adopted by BAS to reduce energy usage such as lockouts, scheduling, sequential start-up, resets and diagnostics (Kamm, 2007) (CIRAS, 2005).

Lighting Requirement

MS 1525 is a standard used in Malaysia for designing of energy efficient buildings. The purpose of the standard is to provide a criteria and minimum standards for energy efficiency design, and designers are encouraged to design above the stipulated standards (MS, 2007). The recommended lighting level for offices is 300-400 lux. However, it is not necessary to have 300 lux for all tasks. The most suitable lighting level for working with computer and reading on paper is 50 to 100 lux and 200 to 500 lux, respectively (as cited in Tetlow, 2007). Hence, the solution could be to reduce the ambient lighting level and use task light when more lighting is needed.

METHODOLOGY

The fine-tuning process is a simple four-step method, namely 1) Conduct background study, 2) Collect data and analyse, 3) Implement changes and monitor, and 4) Conduct survey and verification.

Background Study

ST Diamond building started operation in June 2010 as the new headquarter for Energy Commission of Malaysia in Putrajaya. The building's gross floor area (GFA) is 14691m^2, which consists of eight storeys above ground, and two below ground for car park. The façade is fully glazed and at 65 degree slanting from the horizontal at four side, which resemble the shape of a diamond. This aim of this design is to achieve reduction for radiative heat gain from the sun. A central atrium is designed in order to have more daylight penetration into the building. The BEI is very low at average of 65kWh/m^2/year due to the use of energy efficient ACMV system, efficient lighting system and other energy efficient equipments.

The ACMV system of ST Diamond building consists of floor slab radiant cooling (FSC) and variable air volume (VAV) air conditioning system. The sensible heat is taken care by the FSC system and the latent heat by the efficient VAV air conditioning system. The FSC is running at night from 10pm to 6am on weekdays, and 8pm to 6am on Sunday to Monday morning with fixed supplied chilled water at 19^{o}C from the district cooling pant (DCP). The DCP is also providing chilled water at 7.5^{o}C for air-cooling to the air handling unit (AHU). Operational hours for AHUs are 7.30am to 6pm on weekdays, and 7pm to 8pm on Sunday night to dehumidify the air.

50% of the building GFA is designed with daylight factor of not less than 1%. This is achieved with multiple daylight system such as façade mirror light shelf system, atrium daylight system and roof light system. Office area is installed with energy efficient T5 fluorescent tube and lighting designed at 8.6W/m^2. The lighting circuit is well planned with circuit running parallel to the building façade and atrium. A daylight sensor is used to control artificial lighting in order to provide sufficient illuminance level of 300 lux.

Building Automation System in ST Diamond Building

The BAS for ST Diamond building is separated into two units with one handling the operation of the building services (building management unit) and the other receiving and processing the information gathered by the sensors and meters (energy management unit). More than 3000 connected physical points and 245 parameters are being monitored by the BAS. The monitored parameters are categorised into six groups. Parameters of interest for this study are 1) Computation of energy

consumption, 2) Indication of instantaneous power intake of electric motors, 3) Indication on operational status of HVAC system and 4) Reading of daylight illuminance.

Operating Cost

There are two energy providers for ST Diamond building which are the energy provider for cooling in form of chilled water from the DCP and the electrical power provider (TNB). There are two types of charges for subscribing to the DCP, which is the metered variable charge and maximum peak-load demand charge. The user is required to declare a maximum peak load demand, which is 310 refrigerant ton (RT) for ST Diamond building, and pay according to the fixed declared amount monthly. On the other hand, energy provided by TNB is charged according to monthly consumption without having a charge for maximum peak load demand.

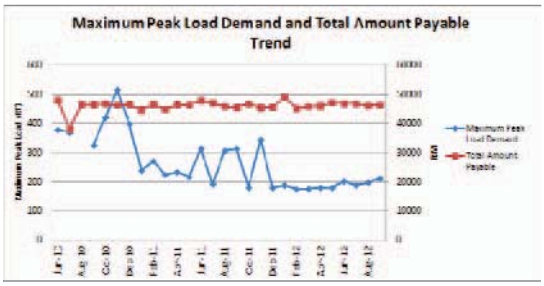


Figure 2: Maximum peak load demand and total amount payable trend

As shown in Figure 2, the blue and red lines indicate the maximum peak load demand and total amount payable to the DCP, respectively. It is observed that the total amount payable is stable in the range of RM45, 000 to RM50, 000 per month. The maximum peak load demand fluctuated until it became relatively stable in 2012.

Analysis of Data

A large data quantity of approximately 28 months of data available for the purpose of this assessment, therefore, the data was reduced for detail analysis to avoid time wastage on an overly huge database. Data collected was rearranged in Microsoft Excel for purpose of further analysis.

Data Analysis on Cooling Energy Usage

Cooling energy is calculated with the formula below:

$$\dot{Q}[kW] = c\left[\frac{kJ}{kg.K}\right] \times \dot{m}\left[\frac{kg}{s}\right] \times \Delta T[K] \qquad (1)$$

Due to the flow rate measured in volume per time, the mass flow rate is converted to volume flow rate and the equation is modified as below for ease of calculation:

$$\dot{Q}[kW] = \left[4.1813\frac{kJ}{kg.K} \times \dot{v}\frac{m^3}{hr} \times (T_r - T_s)K\right] \times 1000\frac{kg}{m^3} \times \frac{1\,hr}{3600\,s} \qquad (2)$$

Analysis for FSC System

There are two combinations of data to calculate the energy usage for FSC. The first combination or method 1 is to use the chilled water (CW) return and supply temperatures and flow rate at the manifold stations. The second combination or method 2 is to use the CW supply and return temperatures at the secondary common header and summation of flow rate at the manifold stations. Due to AHU and fan coil units (FCU) not operating during the operation of FSC and vice versa, chilled water flows through the secondary common header during FSC operation period is solely cater for FSC.

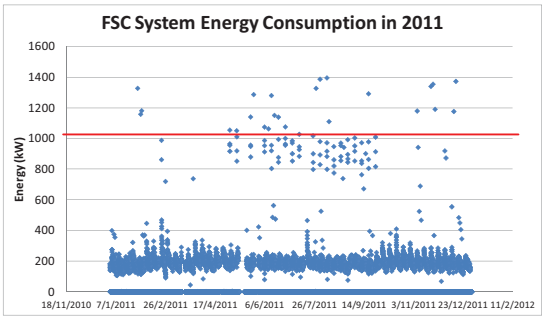


Figure 3: FSC Energy consumption 2011

The x-axis and y-axis represent the date and energy consumption in kW, respectively. The red line is the declared maximum peak load demand of 1000kW. The FSC system is normally operating between 100 to 300kW. At certain periods, the FSC is operating with abnormally demand in between 800 to 1000kW and beyond. Such high demands need to be reduced to save on operation cost. Therefore, weekly energy consumption trend for FSC was plotted for 2011 and 2012.

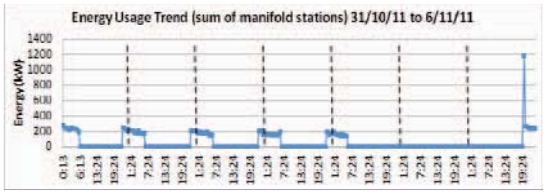


Figure 4: FSC energy usage trend from 31/10/11 to 6/11/11

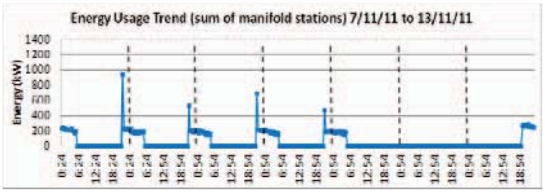


Figure 5: FSC energy usage trend from 7/11/11 to 13/11/11

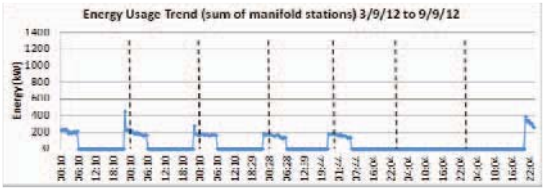


Figure 6: FSC energy usage trend from 3/9/12 to 9/9/12

The x-axis and y-axis represent time and energy in kW, respectively. The black dotted line is marked at the end of a day. It is observed that start-up peak only occurs on some days. Hence, a calculation with a different combination of data is performed to investigate the results.

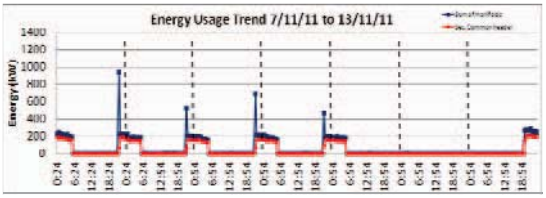


Figure 7: FSC energy usage trend from 7/11/11 to 13/11/11

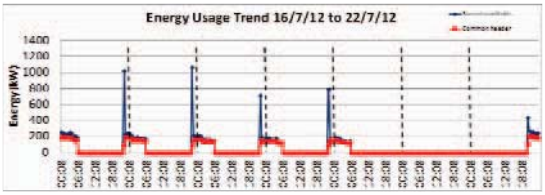


Figure 8: FSC energy usage trend from 16/7/12 to 22/7/12

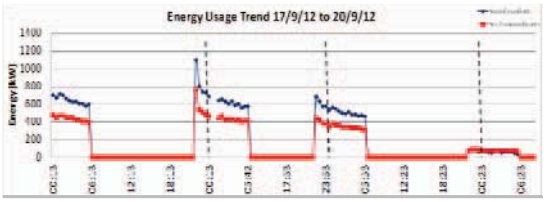


Figure 9: FSC energy usage trend from 17/9/12 to 20/9/12

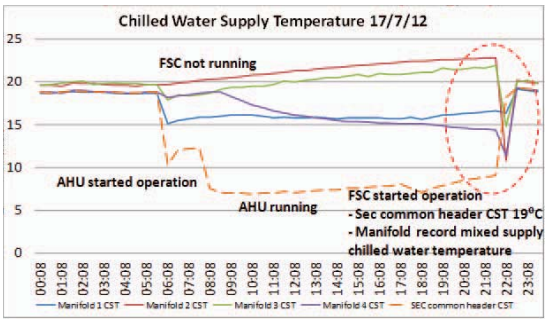


Figure 10: Chilled water supply temperature at the manifolds and secondary common header on 17/7/12

The dark blue line and red line represent energy usage trend calculated with method 1 and 2, respectively. It is observed that the start-up peak does not appear in calculation with method 2 except on 16/9/12 to 18/9/12 (Figure 8) due to the system overrode to be operating manually, and was supplied with 8 to 10°C chilled water. It was found out that the high start-up peak calculated with method 1 is due to sudden drop in the supplied chilled water temperature during start-up. This is the result of mixing between the trapped chilled water in the pipeline supplied for the AHU during daytime (6 to 7°C) and the chilled water supplied to FSC system (18 to 19°C) at night.
The x-axis and y-axis represent the time and chilled water supply temperature, respectively. Whereas, the solid line and dotted line showing the supplied chilled water temperature at manifold stations and secondary common header, respectively.

To conclude, calculation with method 1 yielded false result, which indicates that the start-up peak is not valid. Therefore, no improvement measure is proposed.

The FSC system was manually overridden on 16/9/12 to 18/9/12, which saw cooling energy demand averaged at 300kW to 400kW compared to 200kW on other days. This event has caused condensation at certain area in the building such as the pantry. As such, it is also suggested that the FSC has to be strictly operated to design set point and manual operation should be prevented. Data logger was installed on several locations before this event for which ceiling surface temperature, room temperature, relative humidity and dew point was recorded.

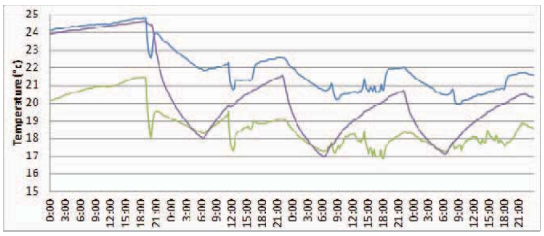


Figure 11: Room temperature (blue), ceiling surface temperature (purple) and dew point (green) at Level 2 pantry from 16/9/12 to 18/9/12

The AHU normally starts up at 7pm on Sunday (16/9/12) to reduce the air humidity in order to prevent condensation. The sudden drop in dew point is corresponding to the starting up of the AHU. Because the FSC system on 16/9/12 to 18/9/12 was supplied with 8°C to 10°C of chilled water, the ceiling surface temperature dropped below the dew point and resulted in condensation.

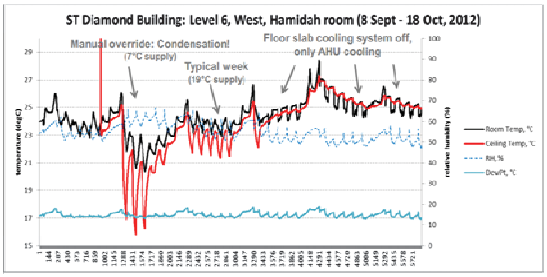


Figure 12: Room temperature (black), ceiling surface temperature (red), relative humidity (dotted) and dew point (blue) at level 6, west side, during operation of FSC with overcooled chilled water, normal mode and not operated

Data logger was also installed at west side of level 6 and the data showed the temperatures and dew point pattern during overcooled mode, normal mode and not operated mode.

Analysis for AHU

The energy usage of the AHUs is calculated with flow rate, chilled water supply and return temperature at the AHU common header. The energy consumption of the AHUs for 2011 was plotted in Figure 12.

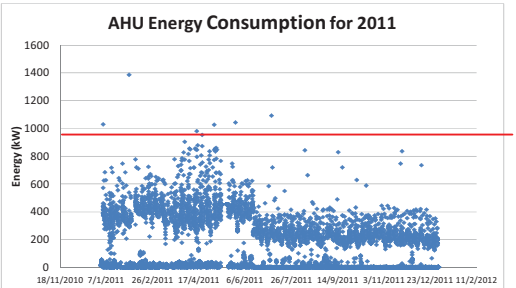


Figure 12: AHU energy consumption 2011

According to Figure 12, the AHUs are operating in the range of 200 to 600kW in the earlier days and later become stable at the range of 100 to 400kW. This is due to difference in the set point used. AHU weekly energy usage trend is plotted to identify the start-up peak.

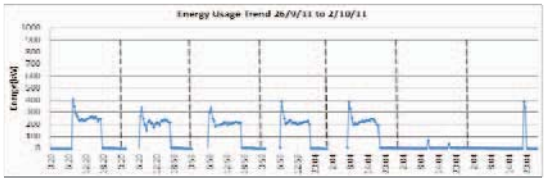


Figure 13: AHU energy usage trend 26/9/11 to 2/10/11

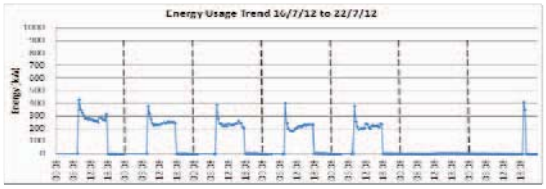


Figure 14: AHU energy usage trend 16/7/12 to 22/7/12

It is observed that the start-up peak occurs consistently for operation of the AHUs. This is due starting up of all AHU at the same time in the morning. Therefore, two methods could be applied to cut down the start-up peak, which is sequential start-up of the AHUs at different levels or a gradual increase of chilled water pump speed to control chilled water supply to AHU. The first method was implemented because it could be done easily by changing the operation schedule of AHU.

The sequence for starting up the AHUs is formulated based on the expected start-up peak. Levels with biggest floor area are assumed to have highest start-up peaks and should begin operation first. After the peak is reduced, subsequent levels with smaller floor area are activated. As a result, a new ACMV operation schedule is formulated.

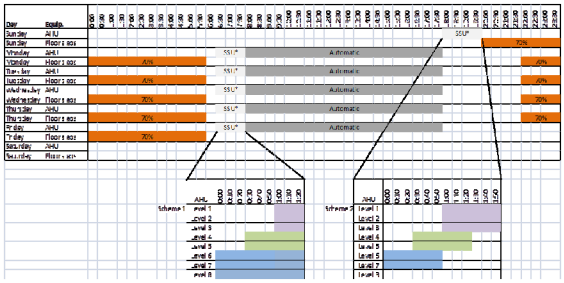


Figure 15: New operating schedules of AHU and FSC including sequential start-up

On weekdays, pre-cooling first starts at 6.30am with level 6, 7 and 8. Level 4 and 5 begin after half an

hour at 7am while level 6, 7 and 8 are still running. Subsequently, level 1, 2 and 3 will start at 7.30am. PAHU at level 8 will start first in order to flush the building with fresh air to achieve good air quality. On Sunday night, only level 6 and 7, 4 and 5, 1, 2 and 3 will start at 6pm, 6.30pm and 7pm respectively, and operates for 1 hour. The cooling energy usage for the AHUs is anticipated to be slightly higher due to longer operating hour.

The maximum energy demand for AHUs and FSCs without start-up peak is approximately 300kW. If start-up peak is avoided, the new declared maximum peak load demand should be at 400kW (114RT) including 100kW as a buffer to avoid frequent exceeding of the limit. Therefore, saving per annum = (310RT – 114RT) x 12 months = 2352 RT or 48.7% saving of operating cost with immediate return on investment (ROI).

Analysis for Lighting

Energy consumption for lighting can be read directly from the BAS database. Lighting usage for normal and essential board is monitored from basement 2 to eighth floor.

The lighting system is controlled by various daylight sensors located at level 1, 2, 6 and 8. There is also a radiance sensor installed on the rooftop in a horizontal position to record radiance intensity from the sky. It can be converted into lux to represent available daylight from the sky.

$$Illuminance\ level, lux\ \left(\frac{lm}{m^2}\right) = radiance\ intensity\ \left(\frac{W}{m^2}\right) \times 120\ \left(\frac{lm}{W}\right) \quad (3)$$

The total instantaneous power intake trend of lighting is plotted and compared against daylight level in order to analyse the daylight responsiveness of the lighting system.

It is observed that the lighting base load is 15kW and average consumption during occupancy in daytime is approximately 25kW, and average consumption in nigh time range from 25 to 45kW.

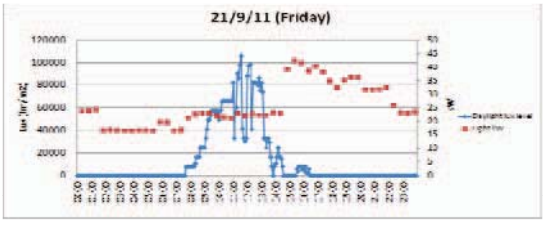


Figure 16: Lighting instantaneous power intake trend and daylight level on 21/9/11

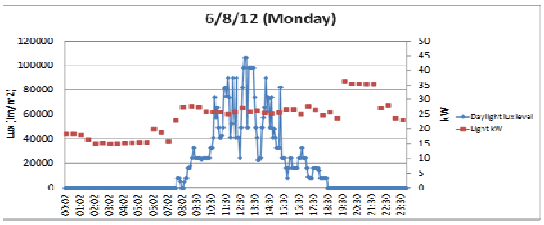


Figure 17: Lighting instantaneous power intake trend and daylight level on 6/8/12

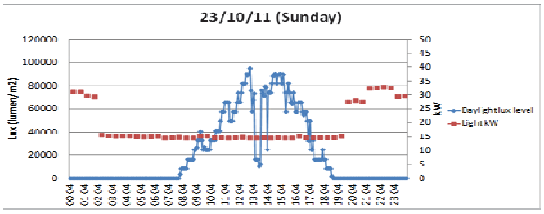


Figure 18: Lighting instantaneous power intake trend and daylight level on 23/10/11

Figures 19 to 21 show the lighting power consumption is further broken down to office levels (L1 to L8, blue), ground floor and façade lighting (red) and basement (green). Daylight level is representing with purple line.

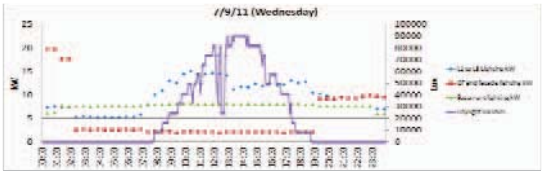


Figure 19: Breakdown of lighting instantaneous power intake trend on 7/9/11

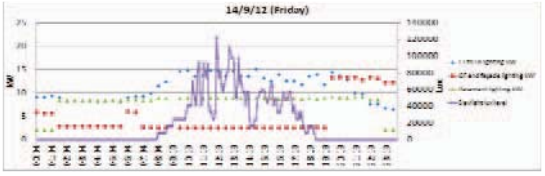


Figure 20: Breakdown of lighting instantaneous power intake trend on 14/9/12

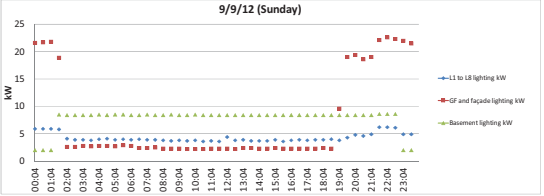


Figure 21: Breakdown of lighting instantaneous power intake trend on 9/9/12

On working days, lighting instantaneous power intake for office levels during office hours ranges from 14kW (1.32W/m^2) to 16kW (1.51W/m^2) on normal days. On weekends and public holidays,

lighting instantaneous power intake for office levels is 4kW (0.38W/m2) to 5kW (0.47W/m2) from 2am to 7pm. The base load is for lighting up the lift lobbies and some common areas.

According to illuminance measurement in Green Energy Office (GEO) in Bangi, Malaysia, occupants are still able to work with the computer at light levels as low as 70 lux. Besides, IESNA suggested that 50 to 100 lux is sufficient for working with computers. Therefore, light switching points controlled by daylight sensors can be lower than current 300 lux set point when supplemented by task light. If the office area and common area illuminance set point is lowered to 120 lux and 40 lux respectively, potential daily energy saving = 91% of total included area x 34.5% non turn on time x (12 hours / 24 hours) = 15.7% of energy saving daily.

Implementation and Monitoring

A proposal for changes was presented to the building facility manager and was granted permission to implementing changes to the AHU operating schedule and lighting switching set point. Due to restriction encountered during the attempt to change, only the lighting switching set point at level 6 was implemented with 150 lux for both working and common area. Changes were monitored for at least a month and result was collected and analysed.

Survey and Verification

A short interview was performed instead of a thorough survey due to the short timeframe given for the study. Feedback was collected with 10 people at level 6 including the building maintenance personnel, building facility manager and the employees. Building facility manager and maintenance personnel were interviewed because they are the parties to receive and handle complain regarding building facilities.

Questions asked in the interview were: 1) Do you notice of any changes in the building air conditioning and lighting system; 2) Is the lighting at your workspace switched on soon enough before getting too dark; 3) How frequent do you using a task light; 4) Do you feel comfortable to work with a task light; and 5) Do you prefer to work with an integrated lighting system with daylight, ceiling light and task light.

RESULTS

Data collected form BAS was check for weekly consumption pattern and start-up peak. Weekly cooling energy trend plot in July to September 2012 is shown as a direct comparison to the result after sequential start-up.

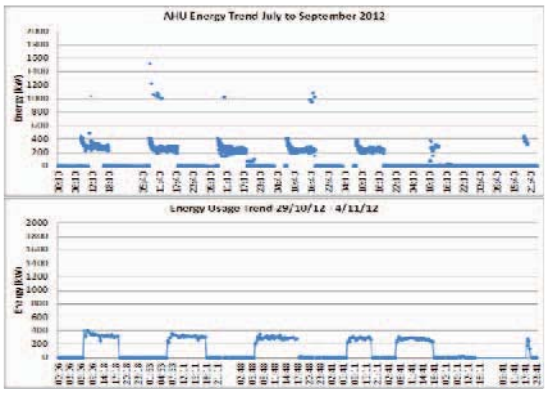


Figure 22: AHU energy usage trend before sequential start-up vs 29/10/12 to 4/11/12

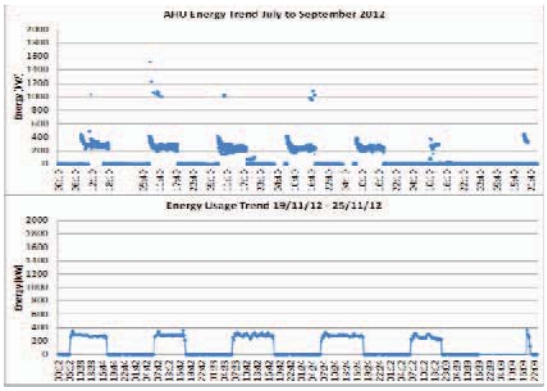


Figure 23: AHU energy usage trend before sequential start-up vs 19/11/12 to 25/11/12

The start-up energy demand is kept below 350kW throughout the monitoring period and the overall maximum energy demand does not exceed 400kW, which is the maximum peak load value recommended for ST Diamond building. The peak during the weekdays occurred at the third half an hour point because of the AHUs at all floors has started up. The peak on Sunday night occurred after half an hour from the first starting up.

Average total energy consumption during weekdays and weekends are 3142kWh and 357kWh, respectively. This is higher compared to the average total energy consumption form June to September 2012 which is 2493kWh and 167kWh respectively, due to longer operation hour.

Lighting energy usage and instantaneous power consumption trend of level 6 is compared to level 5 and 7 due to the smallest difference in floor area and nearest in location.

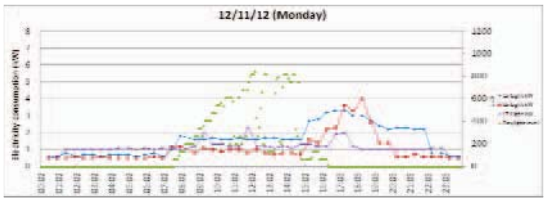


Figure 24: Comparison of lighting instantaneous power trend for level 5 (blue), 6 (red) and 7 (purple) on 12/11/12

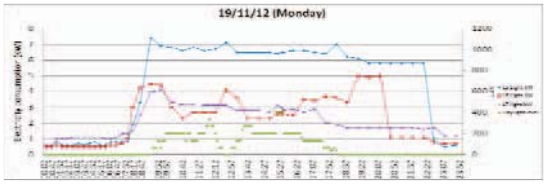


Figure 25: Comparison of lighting instantaneous power trend for level 5 (blue), 6 (red) and 7 (purple) on 19/11/12

The green line represents the daylight level. Lighting instantaneous power trend for level 6 is generally lower than level 5 and 7, despite that level 5 is smaller in floor area compared to level 6 and level 7 is a floor with less occupants. It is also observed that the daylight responsiveness at level 6 is better compared to level 5 and 7, indicated by fluctuation of the electric lighting consumption according to daylight level. Total energy consumption of lighting during the monitoring period at level 5, 6 and 7 is 227.1kWh, 147.8kWh and 192.9kWh, respectively. Average energy consumption for level 5, 6, and 7 is 32.44kWh (19.0Wh/m^2), 21.11kWh (10.6Wh/m^2) and 27.56kWh (11.9Wh/m^2), respectively. Average lighting energy consumption at level 6 during monitoring period is also 13.3% lower compared to period from 27/8/12 to 20/10/12. It is assumed that some of the occupant will utilise the task light if they feel that it is too dim for them to work. However, the average small power consumption at level 6 during working hours is lower during monitoring period compared to before. Usage of task light is low according to the interviewees.

The results from the short interview were that 1) Generally nobody felt any major changes with regard to thermal comfort and visual comfort, 2) The ceiling light switched on before daylight level get too low, 3) Only some of the employees use task light, 4) Some neutral comments received regarding preference for task light because they have never use it. Some feel comfortable working with task light, and 5) Only positive responses received regarding integrated lighting system involving daylight, task light and ceiling light, like the current design in ST Diamond building.

To conclude, the changes made to the building does not disturb the existing good comfort level and at the same time increase the efficiency of the building services.

DISCUSSION

The sequential start-up of AHU has successfully reduced the maximum peak load demand of the AHUs. If a lower maximum peak-load demand is declared to the DCP, operational cost can be reduced significantly by 48.1%. However, the average total energy consumption for after fine-tuning has increased by 5.3%. As a result, the total monthly bill is expected to decrease by 42.8%. This result is 5.9% lower compared to the calculated saving before at 48.7%. This is because the previous calculation is based on similar total monthly energy consumption during before and after sequential start-up.

The lowered lighting switching set point has result in 13.3% reduction of energy usage at level 6 instead of 15.7% as calculated. This is because the prior calculation is based on the set point of 120 lux in office area and 40 lux in common areas. Therefore, the calculated result is quite precise in predicting the saving and the fine-tuning strategy has successfully meeting the expected result.

Many people have the misconception that works should be performed under a bright light especially in Malaysia. However, it is different if daylight is provided. It is demonstrated in ST Diamond building and GEO building that the occupants are still able to work even under daylight levels below 200 lux. If the occupants require more lighting level, they have the flexibility to use their individual task light. The design with integration of daylight, ceiling light and task light is able to reduce the lighting energy usage and at the same time provide a good visual comfort to the occupant.

SUMMARY

From this Building Automation System study, significant room for improvement was found even for a highly energy efficient building like the ST Diamond building. Potential improvements would not be visible unless the building operation is monitored by the BAS. By performing the 4-steps method, it was possible to understand the current state of the building with the data collected by the BAS and further analyse in depth to find the area that need further optimisation. Subsequently, formulate a method to improve the performance of that system and apply the formulated method with the help of BAS. Next, monitoring throughout a period of time and collect the result to check whether there is any improvement. Surveys can be conducted to get the feedback from the building occupants. This method is quite straightforward and proved to be successful in increasing the energy efficiency and reducing the

operational cost of the AHUs and lighting system, and with immediate ROI.

The sequential start-up strategy implemented is expected to reduce the operating cost by 42.8% if a new maximum peak load demand is declared and agreed by the DCP.

Lowering of the lighting set point was observed to reduce energy consumption and increase the daylight responsiveness of the building. If implemented for the entire building, the energy savings for lighting would be 13.3%. At the same time, changes in lighting switching set point do not sacrifice visual comfort of the occupants.

Improvement in energy efficiency and reduction in operational costs of the building services by utilising the BAS have successfully being demonstrated in this study and proven to be simple and effective without spending a huge amount of money.

ACKNOWLEDGMENT

Most grateful thanks to my thesis supervisors, Mr. Gregers Reimann and Professor Michael Kroedel for the guidance, inspiration and assistance. Appreciation should also be addressed to Ms. Hamidah Abdul Rashid, the head of administration and facilities management unit and Mr. Abdul Rizal, maintenance team member for their cooperation and sharing in the knowledge regarding to the ST Diamond building.

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ANNUAL EQUIVALENT SHADING COEFFICIENT (AESC) INDEX FOR THERMAL PERFORMANCE RATING OF FENESTRATION IN SINGAPORE

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ABSTRACT

Fenestrations typically have higher thermal transfer rates than walls and roofs. The heat gain through fenestration therefore contributes a significant portion to the building cooling load in Singapore.

In the present work, a new index, the "annual equivalent shading coefficient" (AESC), was developed for the thermal performance rating of fenestration systems in Singapore. AESC is a new thermal performance index, which is directly proportional to the cooling load introduced by the respective fenestration system.

The AESCs of typical simple glazing systems, simple horizontal overhangs with various project factors (PFs), and advanced thermochromic glazing systems were calculated and analysed. The results show that, glazing systems with a low standard condition solar heat gain coefficient (SHGC) do not necessarily admit less heat under field conditions. For the horizontal overhangs, the AESCs are only weakly dependent on the façade orientation.

INTRODUCTION

The hot and humid climate in tropical regions requires continuous air conditioning throughout the year. Air conditioning equipment consumes a major portion of the energy used by the buildings and heat gain through fenestrations contributes a significant portion to the building cooling loads. It is undoubted that solar heat gain through building envelope is one of the major contributors to the cooling load of buildings in the tropics. A simulation study reported by Chou and Chang (1997) showed that, for a multi-storey commercial building in Singapore, thermal transmission and solar heat gain through building envelope are responsible for 38% of the overall cooling load and solar heat gain alone accounts for 25% of it.

Effective sun shading is therefore critical to the overall building energy efficiency in Singapore. Technologies, such as low-e double glazing unit (DGU) of "low-solar-gain" type and external fixed shading devices (e.g. overhangs and louvers), are nowadays routinely employed in energy-efficient façades. Recently, innovative façade technologies are increasingly used in Singapore. One example is the so-called active façade system, which has optical and thermal properties that can be dynamically changed in response to climate, occupant preferences and building energy management strategies (LBNL, 2002). Switchable glazing (e.g. thermochromic, photochromic and electrochromic glazing) and motorised shading systems are other features of such active façade systems.

One challenge to the industry is how to reasonably rate the thermal performance of the innovative façade technologies particularly the solar heat gain rate. The so-called shading coefficient (SC) is used in Singapore's building code as an efficiency measure for a sun shading device on the façade (BCA, 2008). However, SC is not adequate to estimate the solar heat gain through many complex fenestration systems. For a specific fenestration system, SC is dependent on many factors, particularly the solar incident angle, which is obviously not a constant quantity throughout the day and the year.

The SC is defined as the ratio of the solar heat gain coefficient (SHGC) of the fenestration system of interest, $G(\theta)$, to the SHGC of a standard 3 mm reference clear glass, $G_{3mm}(\theta)$:

$$SC(\theta) = \frac{G(\theta)}{G_{3mm}(\theta)}. \quad (1)$$

It needs to be highlighted that both SC and SHGC are dependent on the solar incident angle, θ. The usual expression,

$$SC = \frac{G}{0.87}, \quad (2)$$

is only valid for the normal solar incident angle, i.e. $\theta = 0$. For other oblique angles, $G_{3mm}(\theta)$ varies between 0 and 0.87. The angle dependency of the reference glass SHGC makes SC less relevant in the real-world application and should only be referred to as a "normal incident angle" solar heat gain performance indicator (McCluney, 1991).

It is obvious that the SCs of shading devices (e.g. a horizontal overhang) are strongly dependent on the geometric relationship amongst the fenestration, the shading device and the sun. In fact, due to the complexity, the SCs of shading devices have to be evaluated for discrete time steps and be represented by time-averaged equivalent values (e.g. BCA, 2008).

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Furthermore, for active façade systems, the SCs are strongly dependent on the environmental conditions and/or control algorithms. For instance, the SC of a thermochromic glazing system is dependent on its thermochromic layer temperature.

In the present work, an annual equivalent shading coefficient (AESC) index was developed, as an alternative approach for the thermal performance rating of fenestration in Singapore. The AESC index is based on simulation results over a full year and takes into account the dependency of heat gain (both thermal transmission and solar heat gain) on the solar incident angle, various environmental factors and active control algorithms. AESC is also directly proportional to the building cooling load introduced by the fenestration.

THEORETICAL ANALYSIS

Steady- state fenestration heat gain

Heat gain through a fenestration is essentially caused by three mechanisms, i.e. 1) thermal transmission (due to indoor/outdoor temperature difference), 2) solar heat gain (due to solar radiation) and 3) air leakage (or ventilation, due to air exchange). The last mechanism is usually evaluated separately. With the considerations of thermal transmission and solar heat gain alone, the steady state heat flux through a fenestration, q_f, can be expressed as (ASHRAE, 2009):

$$q_f = G_f I + U_f \Delta T, \tag{3}$$

where G_f is the fenestration SHGC, I is the solar irradiance, U_f is the thermal transmittance (U-value) of the fenestration, and ΔT is the indoor/outdoor temperature difference.

Overall thermal transfer value (OTTV)

Equation (3) is dependent on many factors, including outdoor climate, indoor environment, not to mention again that the SHGC and U-value are dependent on solar incident angle and/or other environmental conditions. To characterise the annual averaged thermal performance of the envelope of air-conditioned buildings, the overall thermal transfer value (OTTV) was developed (ASHRAE, 1975). The OTTV is expressed as:

$$OTTV = (1 - WWR) TD_{eq} U_w + WWR \cdot SF_{eq} SC_f + WWR \cdot \Delta T_{eq} U_f, \tag{4}$$

where WWR is the window-to-wall ratio, TD_{eq} is the annual equivalent temperature difference across an opaque wall, U_w is the U-value of the opaque wall, SF_{eq} is the annual equivalent solar factor, SC_f is the fenestration shading coefficient, ΔT_{eq} is the annual equivalent indoor/outdoor temperature difference.

By setting $WWR = 1$, the OTTV of the fenestration alone, $OTTV_f$, can be expressed as:

$$OTTV_f = SF_{eq} SC_f + \Delta T_{eq} U_f \tag{5}$$

Equation (5) is similar to Equation (3), with the main difference that annual equivalent values are used as the coefficients in Equation (5). In practice, the empirical coefficients, SF_{eq} and ΔT_{eq}, are obtained from regression analysis of simulation results. The simulation results are dependent on reference room specifications and local climate data.

OTTV is a better performance index than SHGC and U-value, as it represents the annual equivalent heat gain for a specific set of reference room and climate conditions. In fact, OTTV is used as the building envelope thermal performance index by many tropical and subtropical countries (Yik and Wan, 2005), including Singapore (BCA, 2008).

The physical meaning of OTTV is essentially the annually averaged unit envelope area heat flux during the air-conditioned hours, expressed in units of [W/m^2]. OTTV is strongly correlated to the building cooling load (Chou and Chang, 1997), but it does not directly represent the building cooling load.

Cooling Energy Index (CEI)

Recently, Tsikaloudaki et al. (2012) proposed the cooling energy index (CEI) to represent the additional cooling load contributed by fenestration. The fenestration CEI, CEI_f, can be expressed as

$$CEI_f = \frac{Q_{c,f} - Q_{c,no-f}}{A_f}, \tag{6}$$

where $Q_{c,f}$ is the annual cooling load of a reference room with the fenestration of interest, $Q_{c,no-f}$ is the annual cooling load of the same reference room with the fenestration replaced by an adiabatic wall (i.e. with $U_f = 0$ and $G_f = 0$), and A_f is the area of the fenestration.

The numerator in Equation (6) represents the additional annual cooling load contributed by the fenestration. CEI is directly expressed in the form of the building cooling load, i.e. in units of [kWh/m^2] (or [J/m^2] in SI units). CEI of a specific fenestration needs to be evaluated by computer simulations.

Annual Equivalent Shading Coefficient (AESC)

The CEI is an absolute value and it is hence not convenient in product performance comparison and

rating. It is therefore more meaningful to define a new index, based on the relative ratio of the CEI of a fenestration to that of a reference fenestration. To be consistent with the existing practices, it is suggested to use a 3 mm clear glass as the reference fenestration system. The new relative ratio index, the "Annual Equivalent Shading Coefficient" (AESC), of a fenestration of interest, $AESC_f$, can be expressed as:

$$AESC_f = \frac{Q_{c,f} - Q_{c,f,no-sun}}{Q_{c,3mm} - Q_{c,3mm,no-sun}} \quad (7)$$

where $Q_{c,f,no-sun}$ is the annual cooling load of the reference room with the fenestration of interest under the no-sun condition (i.e. with thermal transmission, but without solar heat gain), $Q_{c,3mm}$ and $Q_{c,3mm,no-sun}$ are the annual cooling loads of the same reference room with 3 mm reference clear glass under either the normal condition (i.e. with both thermal transmission and solar heat gain) or the no-sun condition, respectively.

In Equation (7), the ASEC of a fenestration is essentially the ratio of the annual cooling load caused by the solar heat gain of a fenestration of interest to that of a 3 mm clear glass reference system. This definition is in-line with the definition of SC given in Equation (1).

However, in practice, it is actually redundant to compute the thermal transmission and the solar heat gain separately, when the total fenestration heat gain is readily available. Additionally, for Singapore's climate, solar heat gain is the dominant heat gain mode and the heat gain due to thermal transmission is significantly smaller. In fact, in the building code of Singapore (BCA, 2008), ΔT_{eq} in equation (4) is less than 2% of SF_{eq} (i.e. 3.4:211). It is therefore more convenient to absorb the heat gain from the thermal transmission into the solar heat gain and re-define the AESC of a fenestration as:

$$AESC_f = \frac{Q_{c,f} - Q_{c,no-f}}{Q_{c,3mm} - Q_{c,no-f}} = \frac{CEI_f}{CEI_{3mm}}, \quad (8)$$

where CEI_{3mm} represents the CEI of a 3 mm clear glass. AESC of a fenestration is then directly proportional to the cooling load introduced by the fenestration. The effect of thermal transmission is not ignored in the definition of AESC in Equation (8), but is considered as part of the equivalent shading effect. With AESC, it is not necessary to consider thermal transmission and solar heat gain separately.

There are three major differences between AESC and SC:

1) SC is based on the steady state heat transfer through a fenestration, whereas AESC is an annual equivalent quantity;

2) SC represents the solar heat gain reduction performance only, whereas AESC takes into account of both solar heat gain reduction and thermal transmission reduction;

3) SC is typically evaluated at certain standard environmental conditions only (e.g. ISO, 2003), whereas AESC is directly evaluated by computer simulations based on a specific reference room (or building) and the annual weather data.

REFERENCE ROOM DESCIRPTION

A reference room needs to be defined for the calculation of CEI and AESC. The geometry of the

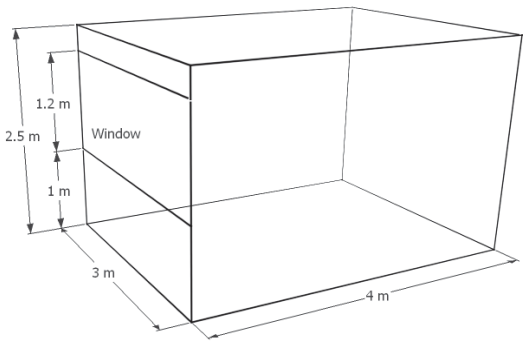


Figure 1: Schematics of the reference room used for calculating the Cooling Energy Index (CEI) and Annual Equivalent Shading Coefficient (AESC).

Table 1. Thermal properties of the 8 simple glazing systems under investigation

No	Short name	U-value	SHGC	SC	$AESC_{north}$	$AESC_{east}$	$AESC_{south}$	$AESC_{west}$
1	3 mm clear	5.33	0.870	1.000	1.000	1.000	1.000	1.000
2	DGU clear	2.83	0.697	0.801	0.804	0.813	0.802	0.819
3	DGU high	2.01	0.615	0.707	0.746	0.756	0.743	0.765
4	Single film	5.51	0.582	0.669	0.689	0.687	0.679	0.672
5	Single tined	5.25	0.424	0.487	0.505	0.504	0.493	0.480
6	DGU low	1.59	0.381	0.438	0.480	0.487	0.477	0.489
7	Single low-e	2.92	0.360	0.414	0.466	0.465	0.460	0.458
8	DGU tined	1.60	0.233	0.268	0.303	0.306	0.301	0.303

Note: the unit of U-value is [W/(m^{2}K)] and all other quantities are unit-less. SHGC = Solar Heat Gain Coefficient; SC = shading coefficient; AESC = Annual Equivalent Shading Coefficient

reference room is shown in Figure 1. The room size is 3 m wide and 4 m deep, with a ceiling height of 2.5 m. The room is a representative office cell of a high-rise office building. Its floor is 12 m above the ground. The window width is the same as the room width. Its height is 1.2 m, and window bottom line is 1 m from the floor. This is a typical configuration for curtain wall façade. The window-to-wall ratio (WWR) is 48%.

For the reference room, all internal walls (i.e. the three walls without windows), floor and ceiling were assumed as adiabatic. The external wall (i.e. the front wall with the window) is exposed to external sun and wind.

For simplicity, lightweight wall construction with thermal insulation was assumed for all walls, the floor and the ceiling. The U-value is 0.4 W/(m^{2}K) for all wall constructions. The window was assumed as consisting of glass only and the window frame effects were ignored in the present study. This simplification is valid as detailed energy calculation is not the simulation objective.

Typical values of solar absorptance of 0.6 and emissivity of 0.9 were assumed for all opaque building elements.

For the usage profile, it was assumed that the office is occupied during weekdays from 9:00 to 18:00 all year long. The space is air-conditioned from 8:00 to 19:00 during weekdays by an ideal air-conditioning system. The room air set-point temperature is 24°C. The heat addition by people, electrical light and electrical equipment were defined as 126 W, 60W, and 250 W, respectively, active during the office hours only.

EnergyPlus software (V7.1, EnergyPlus website, 2013) was used in the computer simulations.

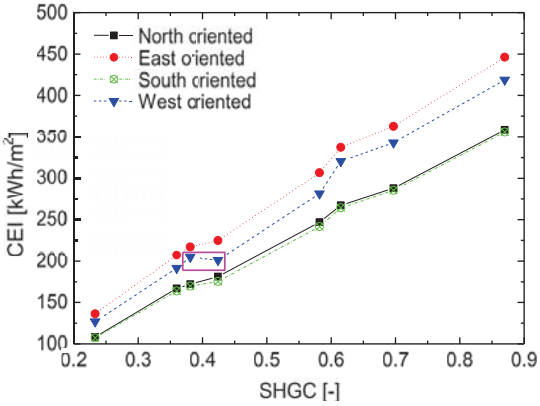


Figure 2. Cooling Energy Index (CEI) values of the of 8 simple glazing systems under investigation as a function of building orientation

AESC OF SIMPLE GLAZING SYSTEMS

Simple glazing systems refer to conventional architectural glazing systems, whose centre-of-glazing thermal performance (SHGC and U-value) can be determined by standard methods such as ISO 9050 (ISO, 2003). 8 typical simple glazing systems

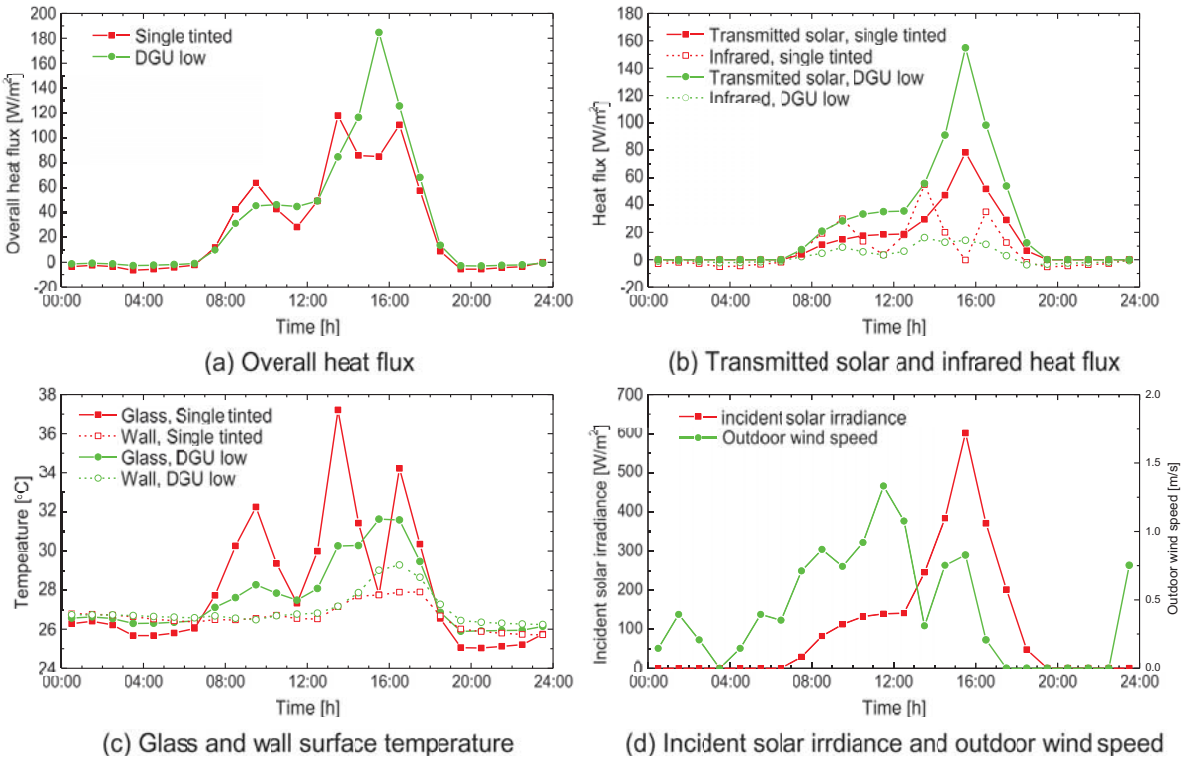


Figure 3: Detailed window heat gain analysis for "single-tinted" and " DGU low" glass types on April 24th in Singapore

were selected for AESC calculation: 1) 3 mm clear glass (referred to as "3 mm clear" in the following); 2) clear double glazing unit ("DGU clear"); 3) high-solar-gain type low-e DGU ("DGU high"); 4) single clear glass with window film ("single film"); 5) single tinted glass ("single tinted"); 6) low-solar-gain type low-e DGU ("DGU low"); 7) single low-e glass ("single low-e"); 8) low-solar-gain type tinted low-e DGU ("DGU tinted"). The 8 glazing systems are numbered according to their SHGC values, from high to low. Table 1 lists the thermal performance properties of the glazing systems, including the AESCs calculated for the four cardinal façade directions. Figure 2 shows the CEIs plotted against their SHGCs.

The CEIs are the highest for the east-oriented façade and slightly lower for the west-oriented façade. The CEIs for the north- and south-orientated façades are very close and they are lower than those for the east/west-orientated façades. As AESC is a relative ratio, the variations of the AESCs between different façade orientations are small. A linear regression analysis was performed. The AESCs for all façade orientations can be expressed as a single linear function of the glazing system SHGC and U-value:

$$AESC_f = 1.119G_f - 0.007U_f + 0.067 \quad (9)$$

The relationship between the CEIs and AESCs for the four cardinal directions can be expressed as:

$$CEI_{f,north} = 358 \times AESC_f \quad (10a)$$
$$CEI_{f,east} = 446 \times AESC_f \quad (10b)$$
$$CEI_{f,south} = 356 \times AESC_f \quad (10c)$$
$$CEI_{f,west} = 419 \times AESC_f \quad (10d)$$

With Equations (9) and (10), cooling loads introduced by simple glazing systems for the four cardinal façade orientations can be conveniently estimated, based on their SHGC and U-value.

It is important to highlight that the empirical linear coefficient for U_f in Equation (9) is negative. It implies that fenestrations with better thermal insulation, i.e. smaller U-value, increase the building cooling load. It is contradictory to the usual practice in the temperate climates, where low U-value is required for improved building envelope energy efficiency. In Figure 2, it also shows that, for the west oriented façade, the glass "single tinted" has a lower CEI than the "DGU low" glass, though the glass "single tinted" has a higher SHGC (as highlighted in the small rectangular box in Figure 2).

In order to understand the mechanisms, detailed analysis were performed for a representative date (April 24). On April 24, the "DGU low" glass admits more heat than the "single tinted" glass. Figure 3(a) shows that the "single tinted" glass dissipates more heat to the outdoor environment during the non-air-conditioned hours than the "DGU low" glass. The room with the "DGU low" glass stores more heat during the non-air-conditioned hours, including night time and weekends. During the air-conditioned hours, the "DGU low" glass also admits more heat in certain periods, including 11:00h – 12:00h and 14:00h – 18:00h.

The solar heat gain through fenestration consists of two components, namely the directly transmitted solar heat and the secondary heat gain (e.g. ISO, 2003). The directly transmitted solar heat is dependent on incident solar energy and glass solar transmittance. The secondary heat gain is dependent on many factors, but mainly on the solar absorptance of the glass, the convective heat transfer rate on the outdoor side, and radiative heat transfer rate on the indoor side.

Table 2 lists the detailed solar optical properties of the "single tinted" glass and the "DGU low" glass. It shows that the "DGU low" has high solar transmittance, i.e. larger directly transmitted solar heat component, but it also has lower solar absorptance and better insulation, i.e. smaller secondary heat gain component. Under the standard SHGC rating conditions, the "DGU low" has a lower overall solar heat gain. However, in the field environmental conditions, its overall solar heat gain is not necessarily lower (as shown in Figure 3(a), 11:00h – 12:00h and 14:00h – 18:00h).

Table 2: Solar optical properties of selected glass types

Short name	Single tinted	DGU low
Solar transmittance	0.179	0.325
Solar reflectance	0.045	0.293
Solar absorptance	0.776	0.382

Figure 3(b) shows that the "DGU low" glass admits more directly transmitted solar heat during the daytime, particularly in the late afternoon for the west-oriented façade. The variation of the radiative heat transfer between the glass and the indoor surfaces are more complicated. For the present environmental conditions, the radiative heat gain from the "single tinted" glass is in fact close to or even lower than that of the "DGU low" glass. This can be explained by the glass and wall temperature variation shown in Figure 3(c). The wall surface temperature is typically around 2°C higher than the room air temperature (24°C). The higher wall temperature reduces the radiative heat transfer rate between glass and wall, to a level lower than that under the standard conditions. The glass surface temperature is influenced by both incident solar radiation and outdoor wind speed, as shown in Figure 3(d). The relatively stronger wind speed between

11:00h and 12:00h causes lower surface temperature of the "single tinted" glass, but the influence on the "DGU low" glass is noticeably smaller, due to their different solar absorptance values.

In summary, the secondary heat gain is strongly dependent on the environmental conditions. Glazing systems with low SHGC under the standard conditions do not necessarily gain less heat, when detailed room and weather conditions are considered. As the secondary heat gain is strongly dependent on glass U-value (ISO, 2003), the negative coefficient for the U-value term in Equation (9) is a correction of the over-estimated U-value contribution under the standard conditions.

The current findings also pose a question of the appropriateness of using SHGC and U-values of fenestration systems directly in building energy performance simulations. It may be more appropriate to input the detailed layer-by-layer glass material thermal and optical properties in the simulation analyses.

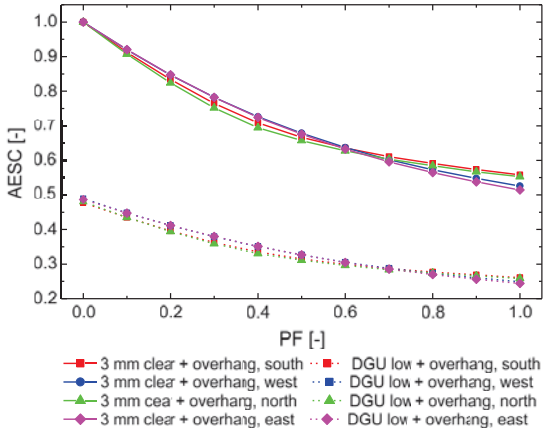


Figure 4: Annual Equivalent Shading Coefficients (AESC) of the combined system with glass and horizontal overhang

AESC OF SIMPLE HORIZONTAL OVERHANGS

Externally fixed sun shading devices are commonly used in the tropical architecture. In the present work, the AESCs of simple horizontal overhangs are also analysed. It was assumed that the overhang is made of a flat plate, directly attached to the top edge of the window. The project factor, PF, of a horizontal overhang is defined as the ratio of the horizontal depth of the overhang, P, to height of the fenestration, H, i.e.

$$PF = \frac{P}{H}. \quad (11)$$

In the present work, 10 PFs, from 0.1 to 1 at a step size of 0.1, were evaluated. The case without overhang can be considered as a special case with $PF = 0$. To reduce the total number of simulations, the horizontal overhang was only combined with the "3 mm clear" glass and the "DGU low" glass for numerical analyses. Figure 4 shows the AESC of the combined system (i.e. glass and overhang) for the two glass types and the four cardinal directions.

The calculation results show that the AESC with horizontal overhang is only weakly dependent on the façade orientation. This observation is different from that reported by Chua and Chou (2010), who observed a stronger dependency of the energy performance of external shading devices on the façade orientation. The method defined in Singapore's building code (BCA, 2008) was used there in the overhang effective shading coefficient calculation (i.e. based on the solar angle and radiation data of three representative days in a year). This simplification as per the building code may result in the difference in the findings.

The other observation from the present study is that the ratios of the AESCs of the combined systems with the "3 mm clear" glass and overhangs to those of the combined systems with the "DGU low" glass and overhangs are relatively constant. It is possible to express the combined AESC, $AESC_{combined}$ as:

$$AESC_{combined} = AESC_f \cdot AESC_s, \quad (12)$$

where $AESC_s$ is the AESC of a shading device, which is a simple horizontal overhang in the present discussion. For the simple horizontal overhang, a regression analysis was conducted (shown in Figure 5) and its $AESC_s$ can be expressed as:

$$AESC_s = 0.402 \times PF^2 - 0.858 \times PF + 0.995 \quad (13)$$

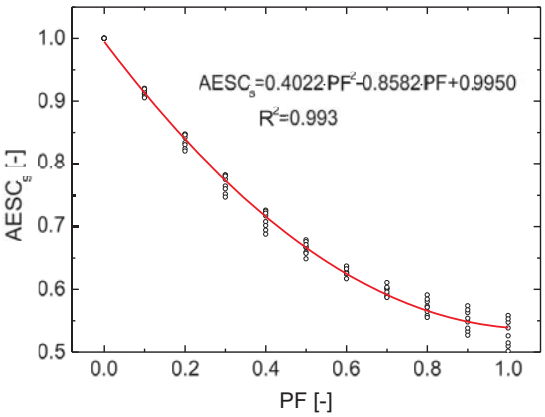


Figure 5: Regression analysis result for Annual Energy Shading Coefficient (AESCs)

AESC OF THERMOCHROMIC GLAZING SYSTEMS

The optical and thermal properties of active façade systems can be dynamically switched, rather than having constant values. It is challenging to rate their annual equivalent thermal performances with conventional indices (e.g. SHGC and U-value).

In the present work, the AESCs of three typical thermochromic glazing systems were evaluated. Figure 6 shows the variations of the SHGCs of the three thermochromic glazing systems (with the short names "thermochromic 1", "thermochromic 2", and "thermochromic 3") as a function of the thermochromic layer temperature. The thermochromic glass properties available in the WINDOW software (V7.1.32, WINDOW website, 2013) were used for the analysis. It was assumed that the thermochromic glass is placed as the outer pane of a DGU with 12 mm dry air gap and a 6 mm clear glass as the inner pane. For convenience, the equivalent SC scale is also shown in Figure 6 (right side vertical axis).

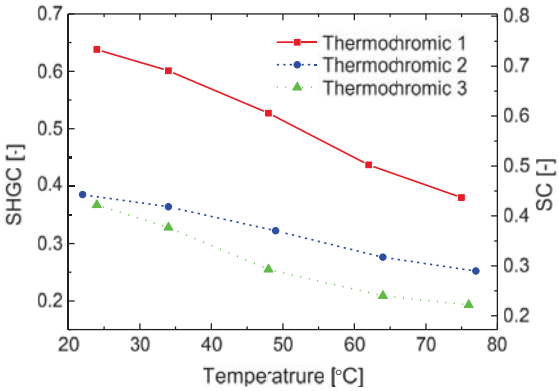


Figure 6: Solar Heat Gain Coefficient (SHGCs) and Shading Coefficients (SCs) of the three thermochromic glazing systems under investigation

Figure 7 shows the AESCs of the three thermochromic glazing systems, for the four cardinal directions. The AESC of the "thermochromic 1" glass (0.71) is only slightly smaller than its clear-state SC (0.73). It implies that most of the time its thermochromic layer temperature is low and the system is close to the clear state. The performance of the "thermochromic 2" glass is similar to that of the "thermochromic 1" glass. The AESC of the "thermochromic 3" glass' (0.36) deviates slightly more from its clear-state SC (0.42).

The AESCs do not vary significantly for different façade orientations. It is believed that the variation of AESCs between façade orientations is strongly related to the secondary heat gain component as well. The data density provided in the WINDOW software is low (see also Figure 6, where only five temperature points are available for each glass type), hence further detailed analysis could not be conducted.

As AESC is evaluated by computer simulations, it can be used to rate the thermal performance of advanced façade systems. The applicable scope is only limited by the modelling capabilities of the simulation tools.

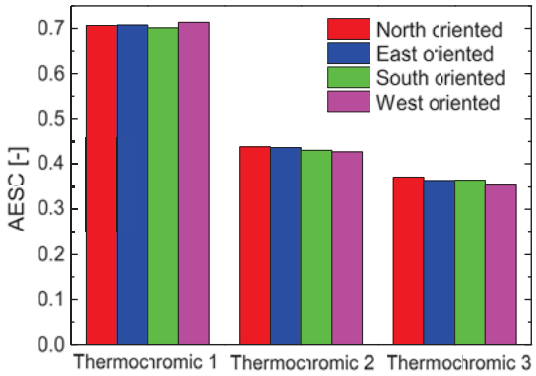


Figure 7. Annual Energy Shading Coefficient (AESCs) of the three thermochromic glazing systems under investigation as a function of facade orientation

CONCLUSIONS

A new thermal performance rating index for fenestration systems, the "Annual Energy Shading Coefficient" (AESC), was developed. AESCs of typical simple glazing systems, simple horizontal overhangs and advanced thermochromic glazing systems were calculated for the four cardinal façade directions under Singapore's climate conditions.

AESC is an annual equivalent performance index and is directly proportional to the cooling load introduced by the fenestration system. AESC considers both thermal transmission and solar heat gain effects. AESC is a more realistic performance index, compared to steady state indices (such as SHGC, SC and U-value) and OTTV.

For the simple glazing systems, it is possible to express the AESC of the four cardinal façade directions as a single linear function of SHGC and U-value. It was found that the coefficient for the U-value term is negative. Detailed heat transfer mechanisms analysis shows that the secondary heat gain component is strongly dependent on the environmental conditions. Glazing systems rated as having lower SHGCs under the standard environmental conditions do not necessarily admit less heat in real-world operating conditions. The negative U-value term coefficient can be considered as a correction of the over-estimated U-value contribution to the SHGC under standard conditions.

The present findings also put the use of SHGC and U-value rated at the standard conditions into perspective when it comes to building energy performance simulations.

For the simple horizontal overhangs, the results show that the dependency of the thermal performance on the façade orientation is weak. The AESC of a shading device could be expressed by a second-order polynomial function of PF (project factor) for all cardinal façade orientations.

For the thermochromic glazing systems, the AESC index is able to properly rate the thermal performance of such active façade systems. In general, AESC is based on computer simulations. Its applicable scope is only limited by the simulation capabilities of the simulation tools.

Some of the finding presented here (e.g. the negative U-value term coefficient in Equation (9), the weak façade orientation dependency of the simple horizontal overhangs) are contradictory to (or different from) the usual practice/experience or other researchers' findings. It urges that detailed fundamental building physics studies, particularly field measurements, are required for facade systems in tropical climate conditions.

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DESIGN & DETAILING OF ADVANCED COMPOSITE RETROFIT SOLUTIONS FOR BUILDINGS EXPOSED TO TROPICAL & MARINE ENVIRONMENTS

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ABSTRACT

Buildings in tropical and marine environments are more at risk of severe deterioration due to corrosion of the existing reinforcing steel. The lost sections of steel lead to reduced shear strength and bending strength in reinforced concrete members. Advanced composite systems are currently being utilized to provide additional strength and protection to structures in these aggressive environments. Over the last twenty years, these Fiber Reinforced Polymer (FRP) systems have been widely used in buildings with an emphasis on seismic rehabilitation and change of use. More recently, these materials have proven their value by providing additional strength, while simultaneously protecting the structure from exposure to the environment. These applications pose unique challenges to both the engineer and the contractor, but they have proven to add long-term value to critical assets. This paper will review the design procedures, relevant testing, and repair projects completed in corrosive environments.

INTRODUCTION

For most marine and tropical environments, the use of reinforced concrete is quite common and has been around since Roman times. However, what has changed in the past 2000 years is the composition of the reinforced concrete. The Romans primarily used rocks and plant fibers as reinforcement, but overtime these reinforcements have been replaced with first iron and now steel. This transition into steel within the reinforced concrete, for in marine and tropical environments especially, has created quite a problem. Given a significant amount of time, moisture, chlorides and other containments will oxidize the steel. As the steel starts to oxidize, the steel itself will expand, which causes the concrete to also expand and eventually crack. This will allow additional water to seep into the concrete more and cause this corrosive process to accelerate even more. Over time, the concrete will delaminate and structural failure will follow. Figure 1 shows an example of a severely corroded concrete structure within the tidal zone of a marine environment.

Ultimately, the structure needs repair and this leaves the owner with only a few options: (1) do nothing, (2) use traditional repair methods to the reinforced concrete, (3) apply fiber reinforced polymer (FRP) composite systems in conjunction with the traditional concrete repair methods, or (4) use FRP only.



Figure 1: Concrete Corrosion within a Tidal Zone

The design and implementation of FRP composite systems for civil infrastructure was actually first adopted from the military and aerospace industries several decades ago. Currently, timber, steel and concrete elements can each be wrapped with FRP composite systems, in most cases as a strengthening element to the deteriorated structures. It has become increasingly popular to use the FRP composite systems as an environmental protection element to both old and new structures, which are susceptible to not only repeated fresh or salt-water immersion, but also freeze-thaw cycles, ice, vessel impact, and attack from marine organisms. Ultimately, with the proper FRP design and detailing, it can help to aid in eliminating any further corrosion.

In this paper, a discussion on current design considerations for FRP, relevant testing for marine and tropical environments and several cases studies are presented. One major goal is to show the effectiveness of FRP composite systems in these environments as a robust retrofit solution.

DESIGN CONSIDERATIONS

Typically, FRP composite systems are designed as an externally bonded element to supplement tension (or steel) the engineer of record wishes was already in the section. For marine and tropical environments, there are two types of FRP strengthening systems typically used: carbon or glass fibers saturated in an epoxy matrix. One of the main reasons engineers like to design with either glass or carbon FRP as a tension supplement is due to the strength similarities to steel. Figure 2 shows a comparison of the stress-strain curves between steel, carbon FRP and glass FRP

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The additional capacity provided by the FRP composite systems can be quantified in terms of shear/flexural capacity, confinement (i.e. lateral confining pressure), and protection by encapsulating the structure, which significantly reduces deterioration by preventing contaminants from entering the repaired section and causing corrosion to take place.

Marine specific epoxy resins have been developed and can be applied underwater by specialized divers, who are certified and trained by the FRP manufacturer. It is important to note that each of these underwater epoxy resins should pass the Aquatic Toxicity Test, to ensure the environment is not contaminated by the retrofit solution. Some types of polymers can be harmful to the environment so the designers must be aware of the precise materials being submitted and be sure to minimize the impact to the environment. Polyester and vinyl ester resins should be avoided due to the high content of styrene. The styrene molecules can diffuse out and pollute the environment. These resins also degrade rapidly in humid environments causing not only pollution but also poor durability of the system.

RELEVANT TESTING

In order to prove the use of FRP composite systems for marine and tropical environments, it is important to discuss relevant testing. Over the past 5 years, there has been considerable research done on the effects of extreme environments on the FRP strengthening systems. Not only researching how these extreme environments affects the strength and stiffness of the FRP strengthening systems, but also how the systems are applied to already deteriorated structures. For simplicity, three testing experiments on FRP systems are presented below, which discusses (1) corrosion testing on the FRP system, (2) freeze-thaw testing on the material properties of the FRP system, and (3) applicable carbon FRP repair techniques in a corrosive environment.

Corrosion Testing, University of Texas, USA (2006)

In 2006, the Texas Department of Transportation (TxDOT) initiated a research program at the University of Texas in order to determine the long-term effectiveness of FRP composite systems to extend the life of reinforced concrete structures. The research program included several stages, but the primary stage, that will be the focus hereinafter, was to understand how effective the FRP composite system is in preventing corrosion activity. This research area is significant, because it is already widely known that the FRP composite system can be used to strengthen many elements of structures, but can the system be effective to prevent corrosion, which is present in marine and tropical environments. This means the research program was broken down into two specimen categories: un-wrapped and wrapped.

Several different variables were investigated to understand the effectiveness of the FRP strengthening systems: cast-in chlorides, cracks, repairs, wet surfaces, wrap length, and presence of corrosion inhibitor. However, the results presented in this section only look at the cast-in chlorides and use of the FRP as a repair method to keep additional chlorides from entering the system.

As of 2006, a total 43 specimens were under exposure. The specimens were broken into two categories, which has been discussed above and no additional corrosion inhibitors added to any of these specimens. Each specimen was placed, for at least 3 years, into an exposure tank with a 3.5% saline solution in order to accelerate the corrosion process (due to the multiple stages of the research program, some of the specimens spent more than 3 years in the exposure tank). This allowed one part of the investigation to primarily focus on the effectiveness of the FRP strengthening system on typical reinforced concrete structures.

The results were presented in three different methods: (1) visual observations of corrosion, (2) half-cell potential contours, and (3) chloride content profiles. Each gave a direct comparison between the two specimen types.

For the specimens cast in 1998, the FRP composite system was effective to inhibit the corrosion process. Figure 3 shows a completely wrapped column when it had been removed from the exposure tank after 3 years. As can be observed, there was only minimal water penetration to the concrete surface, but nothing significant compared with the un-wrapped specimens (Karpate et al, 2006).



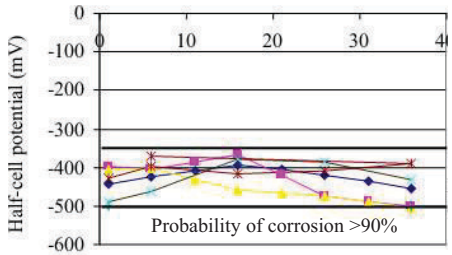
(a) Completely Wrapped Column (b) Column After Wrap Removed

Figure 3: Completely wrapped specimen after testing

In Figure 4, the half-cell profiles for both the un-wrapped and wrapped specimens are presented. The half-cell potentials are effective in determining if the

probability of corrosion present in the system is either very high or low. However, for potentials in between, this method becomes less accurate in predicting the probability of corrosion. For the un-wrapped specimens, the half-cell potentials ranged between -350 mV and -550 mV, which indicates there is a high probability of corrosion. However, for the fully wrapped specimens, the potentials ranged from -200 mV to -500mV, which lands within the range of voltages where it is hard to determine the corrosion probability. In the end, it became increasing clear that with increased cycles in the exposure tank the level of corrosion becomes increasingly difficult to predict, but it was not a complete loss. Based on the profiles in Figure 4, there is a strong indication that the addition of FRP helped to reduce the likelihood of corrosion (Karpate et al, 2006).

(a) Half-Cell Potentials for Un-Wrapped Columns



(b) Half-Cell Potentials for Wrapped Columns

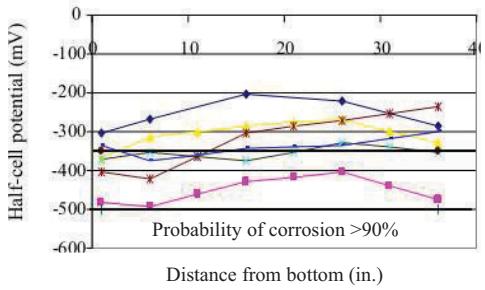
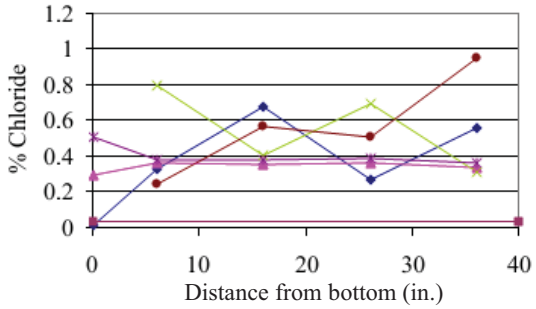


Figure 4: Half-Cell Potential Results for both Un-Wrapped and Wrapped Columns

While in Figure 5, the chloride contents and profiles for both the un-wrapped and wrapped specimens are presented. From the results, it is clear the FRP composite system acts as a barrier to ingress of outside chlorides. For some of the wrapped specimens, in this part of the experimental program, were un-wrapped for the top 24 inches. It is clear in the un-wrapped sections the percent of chloride in the column is higher than in the wrapped sections. It was determined that the in-built (already existing) chloride content as a percentage of weight in the concrete is 0.137%. This means any percentage of chlorides above this value will have a high probability of corrosion to develop. For the un-wrapped specimens, the chloride contents are quite a bit higher than the threshold value. For the partially wrapped columns, the chloride contents are higher for the un-wrapped than the wrapped portions. It is interesting to note near the end of the wrapped portion there was a high chloride content, which is accounted for due to the exposed ends. Overall, the chloride content and profiles help to show conclusively the effectiveness of the FRP composite system (Karpate et al, 2006).

(a) Chloride Content Profiles for Un-Wrapped Columns



(b) Chloride Content Profiles for Wrapped Columns

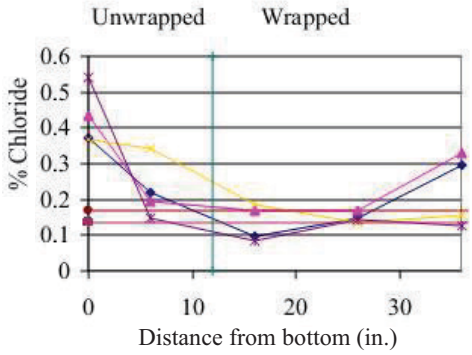


Figure 5: Chloride Content Profiles for both Un-Wrapped and Wrapped Columns

Ultimately, two major conclusions are drawn from this research program. First, the FRP composite system is effective to reduce the corrosion activity in the test specimens. The FRP was able to create a barrier, which limited the migration of chlorides over the height of the column (Figure 5). Not only were the chloride concentrations in the wrapped regions lower than the threshold values, but the half-cell potential readings were higher in the wrapped portions (indicating a reduced probability of corrosion). Second, for high corrosive environments, i.e. marine and tropical, the use of the FRP composite

systems has a high likelihood of extending the life of the reinforced concrete structure.

Long-term Water Immersion, Metropolitan Water District of Southern California (2008)

Both tropical and marine environments are characterized by repeated exposure to water. This is also a characteristic when considering applications in water transmission pipes. A testing protocol was developed in 2000 by the Metropolitan Water District of Southern California (MWD), who was well aware of the variety of durability testing available for carbon FRP composite systems. Since, 1997, the use of carbon FRP to strengthen prestressed concrete cylinder pipes (PCCP) and other water transmission structures has been a common repair option. However, there was significantly less information or testing protocols for long-term durability studies of the carbon FRP composite systems when submerged in water. Considering the carbon FRP systems, when used for pipeline applications, would need to be designed for long-term immersion in water. The study was designed to assist engineers and pipeline users in establishing the applicability of a carbon FRP composite system as a long-term repair system, based on the long-term immersion testing performed.

In order to understand the properties of carbon FRP materials when submerged in water for long period of time, Fyfe Co. LLC submitted their material samples to MWD as part of their on-going carbon FRP liner research program. The samples remained in the immersion tank from 2000-2008 and then were tested for their residual properties by an independent laboratory to provide long-term durability data (see Figure 6). In conjunction with the third party laboratory experiments, on-site inspections were performed as well. The results from the recent inspection and the laboratory experiments showed negligible change in the performance of the materials thereby supporting previous data on the capability of carbon FRP composite materials as a long-term durable solution for pipeline rehabilitation.



Figure 6: Samples Submerged in a water bath at the MWD Facility

According to the test results shown in Table 1, it can be concluded that the CFRP system possesses good long-term durability performance in water immersion environments. After an eight-year water immersion, the tensile strength and elongation are increased by 8% and 12% compared to the un-aged samples, while the modulus is decreased by approximately 16%. All the tensile properties of water-immersed samples are still higher than the typical data reported in the product datasheet.

Table 1
Testing Results for the Immersed Samples

Properties	***Un-aged Sample*** Average ± STD	***Immersed sample*** Average ± STD	***Data sheet Values (Fyfe Co)*** Typical Test Value
Tensile Strength (ksi)	128.7 ±15.6	139.5 ± 18.5	127.0
Tensile Modulus (10^6 psi)	12.7 ±0.14	10.6 ± 1.23	10.5
Breakage Strain (%)	1.16 ±0.17	1.3 ± 0.1	1.2

Through this testing protocol, the durability of the carbon FRP composite systems was presented. Not only is it important to prove the carbon FRP composite systems are appropriate for strengthening, but also show the material properties have an inconsequential change in the composite's tensile strength and modulus when immersed in the environment for a significant period of time. This research helped to prove the durability of the carbon FRP composite systems when in direct contact with water, which is a common occurrence in marine and tropical environments.

CFRP Repair Methods, University of Texas, USA (2007)

Concurrently in 2007, the University of Texas started a research program investigating the use of FRP as a repair and retrofit option for High Mast Illumination Poles. (HMIPs). Although it is not directly related to the above research, there is still relevant information to be extracted from their results, which shows the use of FRP composite systems as a strengthening tool in corrosive environments.

These HMIPs are quite common in many freeway systems to illuminate large areas. However, a recent study revealed many HMIP foundations built in the

late 1980's near Houston by the TxDOT were developing premature concrete deterioration due to a combination of alkali-silica reaction (ASR) and delayed ettringite formation (DEF). The main goal of the study was to investigate bolts used in the construction, which are now corroded. Both new and damaged specimens were tested, where the damaged specimens were actually poles no longer in use, but were constructed in the 1980s. While the study focused on the deterioration of the anchor bolts, which hold down the poles, the use of carbon FRP was used to wrap the bottom portion of the poles tested in order to eliminate the propagation of ASR and strengthen the pole itself, as shown in Figure 7 (Bae et al, 2007).



Figure 7: Texas DOT testing of Anchor Bolt Pull-out Strength – Test Set-Up

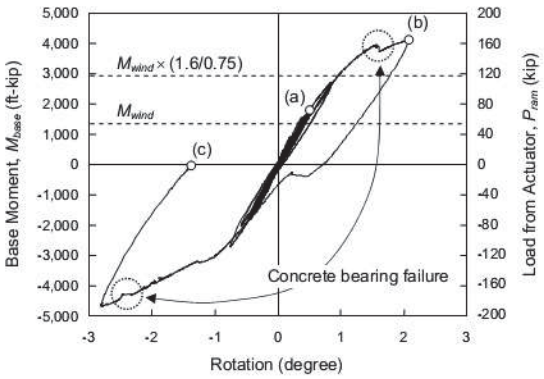


Figure 8: Texas DOT Moment vs. Rotation Results for CFRP Wrapped HMIPs

The carbon FRP composite system was used not only as a barrier to eliminate the possibility of corrosion, but was also designed to strength the HMIPs. However, due to the added strength provided by the carbon FRP, the test was terminated due to the stroke limit of the hydraulic actuator. Based on visual observations, the only visible concrete cracks were formed on the top surface of the shaft and flexural cracks, which formed below the carbon FRP composite system. Figure 8 shows the moment-rotation relationship, which illustrates the addition of the carbon FRP system helped the system to have excellent performance. This test helps to prove the use of carbon FRP strengthening systems to increase the strength of the HMIPs and shows the applicability to use carbon FRP in corrosive environments. The possibility to use carbon FRPs as a retrofit or repair option would not have been available unless it was a proven material for corrosive environments (Bae et al, 2007).

REPAIR PROJECTS

Even with the research presented above, it is also important to present relevant repair projects. This will show the effectiveness of the FRP strengthening systems in the marine and tropical environments. Each project shows a different aspect of the use of the FRP composite systems and the variety of products in the industry available for these sorts of repair projects.

Chart House, USA

In 1999, an upscale restaurant and adjoining apartment complex, which was in poor condition structurally and aesthetically mostly due to exposure to marine weather conditions, was in dire need of structural repair. The restaurant actually sets out into the ocean on concrete pilings and ocean surf is continually surging up against the bottom of the restaurant's floor (Figure 9). The city required a permanent repair of corrosion damage to pilings, beams and slab or the restaurant would be demolished.

The severe deterioration of pilings, beams and slab required a phased retrofit, which would include the strengthening of specific areas and sealing the entire underside of the restaurant (Figure 10-Before).



Figure 9: Outside View of the Chart House, Redondo Beach, CA, USA (1999)

A suspended platform was constructed to provide working space for the crew, while at the same time, protecting the beams and slab from the ocean surge. A process of discovery was initiated to remove any unsound concrete. After treatment with a corrosive inhibitor system, the exposed steel and surrounding

concrete was then sandblasted. Next, polymer-modified concrete was applied to reform members to their original shape. The glass FRP and carbon FRP composite systems were applied to strengthen the pilings, beams, and slab. A final application of bi-directional glass FRP composite system was applied as a water sealant to help protect the restaurant from the marine environment (Figure 10-After).

Not only did the repair system help to restore the restaurant, but also gave the structure the additional strength required to bring it back to code and keep the city at bay. One other important note to remember, is this whole process was completed in an environmentally sensitive tidal zone, which means the materials used need to pass all the environmental regulations presented by the government.

Then in 2012, a visit to the site was performed to investigate the long-term durability of the FRP composite systems. Based on the inspection, there was minimal paint repair required, but the composite system was holding up as designed (Figure 11). This is a valuable example proving the durability of the carbon FRP composite systems in this harsh environment.

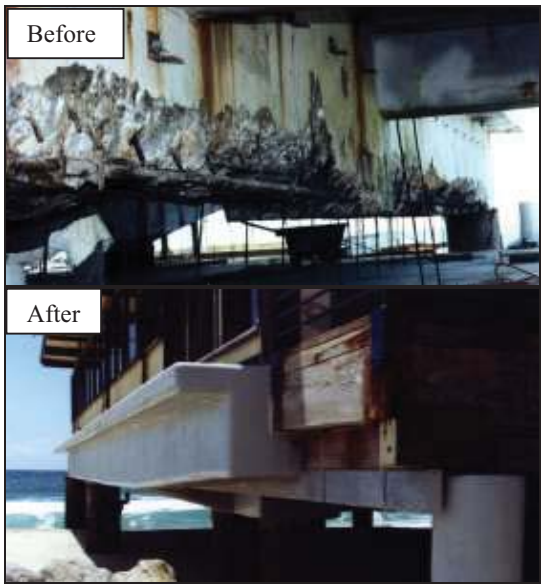


Figure 10: Before and After Pictures of FRP Installation (1999)



Figure 11: FRP system thirteen years after installation (2012)

Malibu House, USA

In 1998, an ocean front residence in Malibu, California contacted an engineer because of a concern they have of the damaged columns and beams under their house. Over the years, just as was the case with the Chart House in Redondo Beach, the columns and beams are constantly being damaged by the pounding surf.

As it turned out, the supporting girders and beams had suffered severe corrosion due to the aggressive marine environment. While the columns had suffered moderate to tenuous cracking and general concrete spalling. After, discussing the possibility of using FRP strengthening systems with a FRP engineer, it was decided to use this system for the structural repair.

The process of repairing and strengthening each of the beams and columns was as follows, which is quite similar to the repair process performed at the Chart House. First, all the loose and damaged concrete was removed and the steel reinforcement lost to corrosion was estimated. Second, a corrosion inhibitor was applied to all the exposed steel to reduce the continued corrosion of the steel. Third, concrete repair products were used to patch the existing column back to its original shape. Finally, once the steel lost to corrosion was estimated the FRP engineers designed the FRP strengthening systems. This allowed the strengthening system to add the necessary reinforcement in flexural, shear and confinement deficiencies. Finally, the FRP strengthening systems were coated with a thickened layer of epoxy coating to protect them from the abrasive nature of ocean tides and sand (Figure 12).



Figure 12: Outside View of the Malibu Residence Home, CA, USA before FRP installation (1998)



Figure 13: Outside View of the Malibu Residence Home, CA, USA after FRP installation (2004)

In 2004, a site visit was also performed at this Malibu residence (similar to the one completed at the Chart House, see Figure 13). It was determined that after 6 years of installation the strengthening system was still up to the same standards as when it was first installed. This project also helps to prove the durability and lasting strength FRP composite systems for tropical and marine environments.

CONCLUSION

Throughout this paper, the justification of FRP strengthening systems in marine and tropical environments was presented. In order to design the FRP strengthening systems, it is important to understand the specific capabilities of each strengthening system, while also determining the design goals of the structure to be retrofitted.

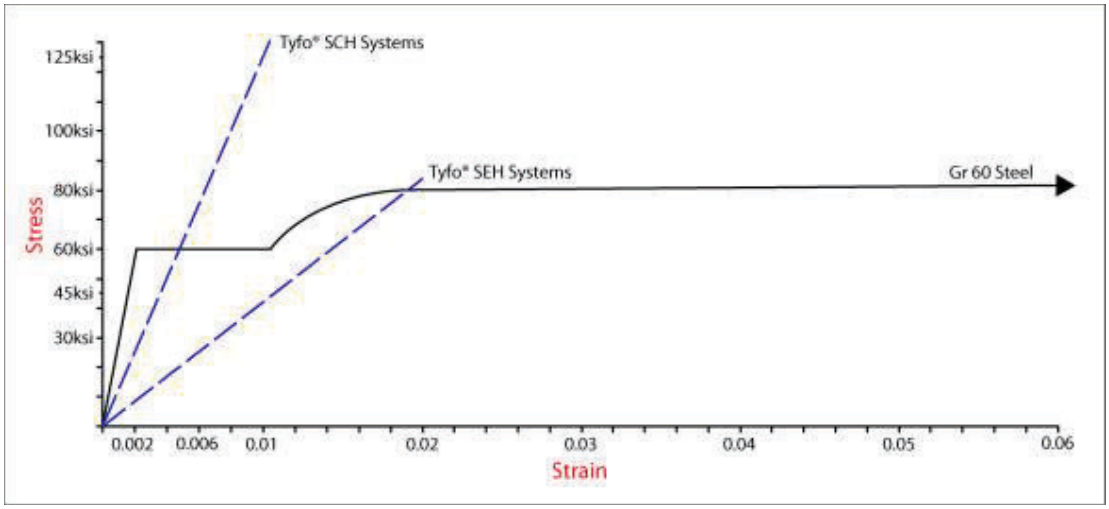
Three different research programs were presented and help to prove the utilization of FRP composite materials for marine and tropical environments. The research proved the residual strength of FRP composites when subjected to extreme environmental conditions, i.e. the FRP is submerged in water for an 8-year period. While in another research program, the validity of the FRP composite system, when used as a barrier against chlorides, was proven to reduce the probability of corrosion and increase the service life of the reinforced concrete.

Finally, sample repair projects were presented. Each project was completed over a decade ago, proving the longevity of the FRP composite systems for the marine and tropical environments. However, each project and application is different. Therefore, it is critical to contact the manufacturer of the FRP composite system in order to understand the proper installation procedures for the FRP composite systems necessary for the project's specific application. Ultimately, the use of the FRP composite systems, as a repair and retrofit material, has proven to be a durable and reliable material for structures in harsh environments.

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Figure 2 – Comparison of Stress-Strain Curves for Grade 60 steel, Carbon FRP, and Glass FRP



IN SEARCH OF CARBON REDUCTION DRIVERS AND PRACTICES FOR THE CONSTRUCTION PROJECTS IN AUSTRALIA

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ABSTRACT

The liability that the construction sector has on carbon emissions has already been justified by statistical records. In Australia, new policies were introduced with an intention to drive carbon reduction in construction operations. A deeper understanding of whether low carbon initiatives like new policies or stringent regulations would be conducive to a change in contractors' behaviour towards emission reduction is desirable. This paper reports a study that investigates how the contractors may enact carbon reduction strategies. Data was collected through a survey conducted in the State of Victoria, Australia. The results indicate that many carbon reduction strategies are rarely adopted in construction projects. Despite 'Reducing Construction Wastes' and 'Complying with the Green Star Ratings' were agreed as the carbon reduction strategies adopted by the respondent's companies, their adoption may not be made in the emphasis for carbon reduction.

Keywords: carbon reduction, behavioural change

INTRODUCTION

In Australia, the construction industry is notoriously known for its intensive carbon emissions. Annually, the construction industry produced approximately 1755.94 Gigagrams (Gg) of carbon dioxide-equivalent (ABS 2008). This figure is miniscule compared to other sectors, as it merely represents 0.3% of the national annual emissions (ABS 2008). However, this figure merely takes into account the direct emissions. In construction, direct emissions are regarded as the emissions directly produced from the activities in the construction sites only (Acquaye and Duffy 2010).

Nonetheless, if indirect emissions were taken into account, the construction industry would be inevitably crowned as one of the major carbon emission sectors in Australia. Indirect emissions can be defined as the emissions that are consequences of the activities of an organisation but occur from sources owned or controlled by another organisation (EPA 2012). The latest figures published by the Department of Climate Change and Energy Efficiency (DCCEE) (2011) indicates that the construction sector is a major contributor of indirect carbon emissions of the country. It produced 40.1 million metric tonnes of carbon dioxide equivalent (mtCO2e), sourcing 20.1% of total emitted carbon throughout all sectors. The figure justifies the liability of the construction industry has on carbon emissions. In this connection, carbon released through construction activities is significant and must be properly controlled and reduced.

In recent years, researchers have put forward a number of strategies to foster carbon reduction in construction projects (Baumgartner and Zielowski 2007; Fieldson 2009; Li and Colombier 2009). These include [1] improving the construction material productivity and utility (Baumgartner and Zielowski 2007), [2] reducing embodied energy consumption during construction operations (Suzuki et al. 1995) [3] advancing construction design to maximise energy efficiency and [4] developing benchmarking mechanisms for evaluating the life-cycle environmental impact of construction facilities (Cuéllar-Franca and Azapagic 2012; Fieldson 2009). Furthermore, the Federal and State Governments of Australia also joined hands with local professional bodies to establish benchmarks of carbon emissions suitable for the construction industry. Two prime examples of benchmarking are the Green Star and National Australian Built Environmental Ratings Scheme (NABERS), in which both tools give an overall rating of a building's design.

In spite of the existence of benchmarking, the construction industry is still being criticised for being slow in transforming their carbon intensive behaviour. This can be explained by the fact that both Green Stars and NABERS are not compulsory for private construction developments. Furthermore, the additional cost due to the implementation of Green Stars and NABERS may have negligible effect on the developers as this can be passed onto the customers. Acquaye and Duffy (2010) shared this viewpoint in their study and identified that contractors are not responsive to the request of self-regulations. In this regard, what is the missing link of fostering carbon reduction in construction?

Collectively bound by the project-based collaboration mechanism, contractors may be unable to change their behaviours in isolation (Spiegel and Meadows 2010). This should be noted that while the contractors supply the front-line workforce for construction operations, they have neither a contractual right nor a responsibility to challenge the choice of carbon-intensive building materials and operations. In this aspect, the developers and their management

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consultants should share the responsibility. However, from a developer's perspective, reducing carbon in construction designs and operations may incur additional project costs that may subsequently erode profits (Spiegel and Meadows 2010). Findings of some recent case studies are coherent with the above arguments. It was reported that most construction designers and contractors in the United Kingdom did not follow the low-carbon best practice guides published by the government (Sorrell 2003).

The above may help to explain why contractors have been criticised for being slow in transforming carbon reduction strategies into actions. One way to foster strategy adoption is by devising drivers of behavioural change. In recent years, respective changes in government policies were observed to foster the contractors' adoption of carbon reduction strategies. For example, the Australian Federal Government passed the first carbon tax legislation in October 2011. While the effect of carbon tax is still yet to be revealed, it has aroused much debate as to whether it would induce any behavioural change (Deane 2011; Singer 2009). As such, a deeper understanding of whether low carbon initiatives like new policies or regulations that are more stringent would be conducive to a change in contractors' behaviour towards emission reduction is desirable.

This study seeks to investigate how the contractors in the construction projects may enact carbon reduction strategies. The construction contractors have been urged by the Australian government to contribute to the national commitment on carbon reduction. As the carbon tax has been effective from 1st July 2012, it is time to review whether the contractors have endeavoured to pursue carbon reduction. The associated findings of this study would provide construction stakeholders with valuable insights into devising pragmatic measures to reduce carbon emissions in projects.

This paper commences with a background review of the carbon reduction strategies and the drivers of carbon reduction that are applicable to construction projects. This is followed by a description of the research methodologies, with the research findings then discussed. Finally, concluding remarks and recommendations are made.

STRATEGIES FOR CARBON REDUCTION

In recent years industry reports in relation to devising carbon reduction strategies have been published (ENCORD 2010; GRI 2011). Global Reporting Initiatives (GRI) (2011) specifically developed guidelines for construction organisations to report their sustainability performances whereby their performance is assessed under three key aspects, namely (1) management approach, (2) strategy and (3) profile and performance indicators. However, the guidelines developed by GRI are not project-specific, implying that they may not be effective in evaluating carbon reduction behaviour in the construction projects. The United Nations Environment Programme (UNEP) suggested seven strategies to help the building industry reduce carbon in construction projects. These include (1) working to introduce a carbon trade mechanism for buildings; (2) working with governments to develop policies that make a difference in emissions behaviour; (3) dedicating research and development to zero net buildings; (4) renovating buildings to maximise the reduction of emissions; (5) demonstrating technology on buildings and rented office; (6) moving to holistic and systematic solutions to sustainable buildings; and (7) educating the supply chain (UNEPSBCI 2009).

As with the work of GRI, the guidelines developed by UNEP have not proposed any project-specific measure to evaluate these strategies.

In this respect, the inventory developed by the European Network of Construction Companies for Research and Development (ENCORD) may be deemed more suitable. It is because the proposed inventory evaluates the carbon emitted by contractors in a construction project specifically. The inventory proposes evaluating the carbon emitted under twelve aspects as shown in Table 1, with methods for measuring the emission amounts. This study adopts the work of ENCORD (2010) and proposes that the up taking of carbon reduction strategies by construction contractors can be evaluated under these twelve aspects.

DRIVERS OF CARBON REDUCTION

Researchers have been striving to devise strategies to reduce the carbon emitted during construction operations (Crawford and French 2008; Hendrickson and Horvath 2000). However, it is not well acknowledged that strategies adoption is a behavioural matter of an organisation. To drive changes, governments intended to charge on carbon emissions by a mean of emissions trading schemes or tightening regulations (RAE 2010). It is anticipated that construction organisations will persevere with their efforts to reduce emissions from their construction operations, in face of the mounted pressure of additional costs.

Indeed there have been policies like carbon tax and emission trading schemes proposed or even enforced in some countries to significantly reduce carbon emissions (DCCEE 2011; Sathre and Gustavsson 2007). While on the outskirts they may seem different, the rationale behind these policies is no different to a 'penalty' mechanism. Generally, emission trading scheme policies operate by means of

issuing a limited amount of tradable permits capping the total national emission volumes within a targeted level. By reducing the quantities of those permits over time, should the volume of carbon emissions remain unchanged, there will be a rise in the carbon price. On the flip side, revenue generated from carbon tax or trading schemes can be used to subsidise other low carbon technologies such as green electricity (DCCEE 2011; Schleich et al. 2009). These policies could somehow induce behavioural change within organisations, especially when they begin to realise the penalties they are paying are more costly than taking alternative actions to cut down on emissions.

However, within various industries, the idea of introducing penalties has caused much debate as to whether it will achieve the desired outcome (Green 2008). Osmani et al. (2008) believed that rewards are more effective to encourage behavioural change than penalties. Lewis et al. (2009) pinpointed that government 'reward' schemes can motivate organisational engagements in carbon reduction and tax rebates can provide essential rewards to encourage organisations to invest in carbon reduction (PricewaterhouseCoopers 2009). Alternatively, capital subsidies, grants, and loan schemes can be introduced to encourage organisations to bring in new strategies to reduce carbon emissions (UNEPSBCI 2009).

'More stringent standards' can be another key driver towards carbon reduction. Working towards the goal of achieving 'new buildings will be close to zero-energy' by 2021, the European Union has introduced stricter energy performance standards for buildings (HMGovernment 2009; RAE 2010). The tightening of standards would cause designers and contractors to rethink their way of operating. For example in terms of selection of materials for their facilities, they will be more cautious especially for those high in embodied carbon (HMGovernment 2009). In Australia, the Australian Building Codes Board (ABCB) has introduced NatHERS which serves to establish a common-ground for rating building energy efficiency (Iyer-Raniga and Wong 2012). Some State Governments in Australia such as Victoria have tightened their regulations to disapprove new construction or alteration works that fall below NatHERS's 5-star standard (Iyer-Raniga and Wong 2012). The introduction of these drastic regulations has been seen as the first step towards forcing behavioural changes in the construction sector (Horne and Hayles 2008).

On the other hand, the Royal Academy of Engineering, UK has emphasised the importance of 'training and education' in enabling behavioural change in emission reduction (RAE 2010). It pinpoints that the construction sector is not well equipped to achieve the proposed 25% cut in carbon emissions through new building regulations. It is deemed 'a dramatic up-skilling' of construction contractors will be needed to meet the requirements of new building regulations. Training and education has also been addressed by RAE (2010) as an important way to facilitate the adoption of carbon reduction strategies within construction firms. As echoed by (Manley and McFallan 2006) who emphasised the need for new graduates in the industry to be educated and trained on new emission reduction practices. The operational statements of the above carbon reduction drivers are listed in Table 2.

Table 1: Carbon reduction strategies proposed by the European Network of Construction Companies for Research and Development (modified from (ENCORD 2010))

CARBON REDUCTION STRATEGIES	OPERATIVE STATEMENTS
Reducing fuel (project) **[S1]**	Reduce fuel for plants and machinery in use on site
Reducing fuel (premises) **[S2]**	Reduce fuel for use in premises which support the company's activities (i.e. offices and godowns)
Reducing process emissions **[S3]**	Reduce carbon emissions from physical and chemical processing involved in the production of mineral products (such and cements) and metal products (such as steel)
Reducing electricity (project) **[S4]**	Reduce electricity for plants and machinery in use on site
Reducing electricity (premises) **[S5]**	Reduce electricity for use in premises which support the company's activities (i.e. offices and godowns)
Reducing imported heat **[S6]**	Reduce heat purchased by the company for use at the company's project and premises
Reducing vehicle fuel **[S7]**	Reduce the use of vehicles travelling on public highways
Reducing the use of public transport **[S8]**	Reduce the use of public transports by the employees
Monitoring sub-contractors **[S9]**	Coordinate with sub-contractors at project level to achieve S1 to S8
Reducing wastes **[S10]**	Reduce construction wastes and the associated transportation for disposal
Reducing high embodied CO_2 materials **[S11]**	Reduce the use of materials with high embodies CO_2 like structural steel concrete, reinforcement, cladding, aggregates and bituminous products
Reducing emissions from the facility **[S12]**	Reduce carbon emissions resulting from the built object through better design

Table 2: Carbon reduction drivers

CARBON REDUCTION DRIVERS	OPERATIVE STATEMENTS	References				
		A	B	C	D	E
Penalty **[D1]**	The introduction of carbon tax / emission trading schemes or similar policy that induce cost for carbon emission	*				*
Reward **[D2]**	The rewarding schemes like tax rebate, capital subsidies and loan schemes that encourage investment of carbon reduction		*	*	*	*
More stringent standard **[D3]**	The more stringent building regulations disapprove works that cannot attain the energy efficiency rating / standards	*		*	*	*
Training and education **[D4]**	The training and education that your company can receive from the government, building authorities and the professional institutes of the sector				*	*

References: (A)(Sathre and Gustavsson 2007); (B)(Schleich et al. 2009); (C)(Acquaye and Duffy 2010); (D)(HMGovernment 2009); (E) (UNEPSBCI 2009)

RESEARCH METHODOLOGIES

The Questionnaire Design

This study received approval from the local university research ethics committee whose clearance standards are outlined in the Australia National Ethics Application Form (NEAF).

To accomplish the research objectives, a questionnaire survey was performed for data collection. The survey questionnaire contains three parts. Part 1 deals with demographic information about the respondents where they were asked to specify a project they had been involved in for at least one year, and the questionnaires of those not having taken part in a specified project for more than one year were discarded. In Part 2, 12 questions engage the extent of strategies adopted in the projects involved by the respondents which were in place to reduce carbon emissions (refer to Table 1). Part 3 seeks to solicit the degree of respondents' agreement on the drivers that enable adaptation to carbon reduction (refer to Table 2).

Data Collection and Analysis

The targeted respondents for this study were assembled from two major sources. Firstly, the registered contractors list, maintained by the Masters Builders Association of Victoria, was adopted. Master Builders is a major building and construction industry association in Australia, and its members represent 95% of all sectors of the Australian building industry (MBA 2011). Secondly, targeted respondents were searched from general browsing on the official web pages of professional institutes including the Australian Institute of Builders, Engineers Australia and Australian Institute of Quantity Surveyors. A list of 300 target respondents who work in contractor firms were identified by employing the above random selection process. The target respondents were invited to participate in the survey via either an online platform supported by Qualtrics or hardcopies delivered by our research team. To avoid disruption to selected hardcopies recipients, the research team has sought permission via telephone before visiting the respective companies in person.

Concerning data analysis, the mean scores of the respondents' degree of agreement on the adoption of carbon reduction strategies and the carbon reduction drivers were compared.

RESPONSE RATE AND SAMPLE PROFILE

150 questionnaires were dispatched. 74 respondents returned the questionnaires with 2 replies excluded due to being incomplete. Hence, 72 valid responses were used representing a 48% response rate. This outcome is comparable with questionnaire surveys of this kind (Lam et al. 2010). The study has attracted a reasonable response rate in comparison to other questionnaire surveys in the construction field normally ranging from 25% to 30% (Wong et al. 2012a). Likewise, the response rate of the current research is similar to that of the study related to carbon emissions conducted by Lam et al. (2010) (such as 100 responses out of 652 questionnaires being sent out or 15% of the response rate). Osmani et al. (2008) yielded a 40% response rate for similar studies given 40 out of 100 questionnaires were received. Both sample size and return rate of this survey study are considered acceptable.

However, as all the respondents are working for the contractors' firms, this data characteristic should be considered when interpreting the findings. Furthermore, it also points to further research using a

larger sample size to validate the current results. Among the respondents' backgrounds, 83% of the respondents have had more than 5 years experience in their respective fields (refer to Table 3). It should be noted that over 20% of our respondents have more than 20 years of project management experience. The creditability of the respondents is indicative of their service to the industry, thus their responses are considered reflective to the industry's views.

Table 3: Respondents' working experience

WORKING EXPERIENCE	NO. OF RESPONDENTS	%
Below 5 years	12	16.7
5 to 10 years	19	26.4
11-15 years	18	25.0
16-20 years	8	11.1
Over 20 years	15	20.8
Total	72	100

FINDINGS AND DISCUSSIONS

Carbon Reduction Drivers

Participants were asked if they agreed with statements D1 to D4 (refer to Table 2) as the drivers of carbon reduction in the construction projects. The scale intervals are interpreted as from 1 "Strongly Disagree" to 7 "Strongly Agree".

As Table 4 indicates, the respondents generally disagree that 'D1: Carbon tax, emission trading schemes or similar policy' is an effective driver of carbon reduction in construction projects (Mean= 3.12; S.D. = 1.62). The result does not seem to align with the government's expectation on the behavioural change led by the carbon tax. A recent study conducted by Wong et al. (2012b) described the carbon tax as a raucous action to change the construction contractors' behaviours. A carbon tax does bring a knock on effect on the cost of construction materials and transportation. However, passing on such cost increases to the end-users seems to be the easier approach to alleviate the adverse cost effect. In addition, except those design and build projects, contractors merely contribute to the design process. Their visions on carbon reduction may not easily be embodied in the projects.

D2: Rewarding Scheme (Mean=3.62, S.D.=1.87) and D4: Training and Education (Mean=3.42, S.D.=1.59) received scores around the mid-value of the seven-point scale. The results may represent that the respondents generally perceived D2 and D4 as the mild tools to drive carbon reduction. The results appear contrary to some review reports published in other countries by professional institutes and government bodies that promoted further education and training in driving carbon reduction (RAE 2010). It may link to the fact that no prominent rewarding scheme is in place in Australia at this time in relation to reducing carbon. Another possibility to a neutral response from survey participants may be due to the limited exposure to the effect of the carbon tax, as it has not yet to be fully measured across the entire construction sector.

Furthermore, this should be noted that stringent building regulations on energy efficiency ratings (D3) may be a popular driver of carbon reduction (Mean= 4.87, S.D. = 1.59). This may be due to the implementation of numerous government scaling and rating systems. The practicality and usefulness in such tools to assess performance of building for both environmental aspects and marketing tools by constructors has made it a trend to implement those requirements which has led to it becoming common practise.

Table 4: Respondents' opinions of carbon reduction drivers and strategies adoption in projects

CARBON REDUCTION DRIVERS		MEAN	STD. DEV.
D1	Penalty	3.12	1.62
D2	Reward	3.62	1.87
D3	More stringent standard	4.87	1.59
D4	Training and education	3.42	1.50
CARBON REDUCTION STRATEGIES		**MEAN**	**STD. DEV.**
S1	Reducing fuel (project)	2.65	1.58
S2	Reducing fuel (premises)	2.59	1.52
S3	Reducing process emissions	2.49	1.32
S4	Reducing electricity (project)	2.59	1.47
S5	Reducing electricity (premises)	2.95	1.68
S6	Reducing imported heat	2.52	1.66
S7	Reducing vehicle fuel	2.09	1.36
S8	Reducing the use of public transport	2.42	1.60
S9	Monitoring sub-contractors	2.54	1.71
S10	Reducing wastes	3.85	2.00
S11	Reducing high embodied CO_2 materials	3.26	1.77
S12	Reducing emissions from the facility	3.99	1.86

Adoption of Carbon Reduction Strategies

Surprisingly, 10 out of 12 strategies are disagreed by the respondents to be adopted in their construction projects to reduce carbon emissions (refer to Table 7). The findings are compatible with a recent study

conducted by Wong et al. (2012) who pinpointed that the Australian construction sector is being passive to reduce carbon emissions because no single contracting party can change his emission behaviours in isolation. Collectively bound by the project-based collaboration mechanism, contractors and consultants are merely project executers who have neither a contractual right nor a responsibility to challenge the decisions made by the developers or their in-house professionals. Unless being initialised by the developers, contractors rarely suggest better operational practices to reduce carbon emissions in the construction projects.

S10 'Reducing construction waste and the associated transportation for disposal' (Mean= 3.85, S.D. = 2.00) and S12 'Reducing carbon emissions resulting from the built object through better design' (Mean= 3.99, S.D. = 1.86) have mean scores greater than 3.5. This indicates that the respondents generally agree that these carbon reduction strategies were adopted in their projects. This may be because the contractors concern with cost of construction waste disposal. The Waste Management Act became effective in Victoria in 1996. Since then, the contractors are charged on a variable amount dependent on the wastes they dispose to the landfill. Waste reduction has become a standard practise on most projects. Waste management plans were introduced in which estimates on how much waste was going to be produced had to be documented, then a status report on what was thrown out and all waste where possible, had to be recycled. Pricing systems in relation to landfill can play a role with pre-separated waste being a cost saver due to the sorting costs with general waste. Various reports indicated that the amount of construction waste dramatically reduced after the enforcement of the Waste Management Act. As such, the primary aim to reduce waste seems to be saving cost, instead of carbon reduction.

In relation to S12 'Reducing carbon emissions resulting from the built object through better design', it is observed that in recent years professional institutes are becoming more enthusiastic in establishing benchmarks of carbon emissions. Green building rating systems like Green Stars and NABERS have started to gain recognition from construction practitioners and the public. The perception of green star ratings amongst the public in some sense has brought the construction practitioners to attention on carbon reduction.

RESEARCH LIMITATIONS AND FURTHER RESEARCH

The findings of this study offer an avenue to interpret the impact of carbon reduction driver on the adoption of strategies in behavioural perspectives. However, they should be taken within the context of several limitations.

Firstly, the findings in this paper are drawn from a pilot study that only includes contractors in the survey sample. The carbon reduction behaviours of the contractors are studied because amongst those construction organisations, contractors are responsible for converting building designs into physical facilities. As a further study, the survey can be extended to include other construction organisations like the developers and the consultants. Secondly, this survey study was conducted at a time when carbon tax had just been introduced in Australia. It can be understood that there may be further studies needed to identify the full extent of the carbon tax, as well as how we can achieve carbon reduction. Furthermore, the results should be taken into context considering the geographical confines of this study. However, considering the careful sampling process and experience of the respondents, the results can only be acknowledged as an intermediate snapshot as the influence of the carbon tax has yet to be realised. Further research into this topic and perhaps a more comprehensive response rate in the years to come should further identify the full extent of the effectiveness of inputted measures as the buffering effect of the carbon tax fades and prices will begin to reflect the impact if at all, significant.

CONCLUDING REMARKS

As with any initiatives, human behaviour and perception can be a major barrier to change. This study advances our understanding by approaching carbon reduction from a different perspective. The finding that the respondent's companies do not adopt most of the carbon reduction strategies in projects aptly reminds us that imposing a carbon tax or tightening regulations are not a panacea to foster behavioural change. More research is needed, particularly relating to addressing the need of the contractors to improve the practicality of the policy to induce carbon reduction in construction operations. On the other hand, the contractors should also explain to the public the difficulties they encounter during the transformation process.

The findings indicate that the construction contractors are in line with the comments made by some scholars as being apathetic to reduce carbon emissions in the construction operations. Although reducing construction wastes and complying with the energy efficiency ratings are commonly used strategies to reduce carbon, their adoption may not be made deliberately for such purpose. The enactment of the Waste Management Act in Victoria has made construction wastes more costly to be disposed to the landfill sites. Tagging products with the energy

efficiency ratings has become an integral part of the real estate marketing strategies. The results indicate that construction contractors are mindful of the financial implications of changing their ways of operations. Further investigation on such an interesting phenomenon is recommended for future research.

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A CONTEXTUAL APPROACH TO GREEN BUILDING REGULATION IN DEVELOPING COUNTRIES

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ABSTRACT

Policy makers for construction industry in developing countries have to strike a delicate balance between promoting continuous, unhindered economic growth and regulating the growth to sustainable levels that doesn't accelerate climate change, environmental pollution and energy shortage.

INTRODUCTION

With rapidly growing economies and a bustling population that has high expectations, urbanisation in most developing countries presents a conundrum to policy makers for the construction industry. The difficult choice they often face is between promoting continuous, unhindered economic growth and regulating the growth to sustainable levels that doesn't accelerate climate change, environmental pollution and energy shortage. Having seen the adverse impacts of unregulated growth, most countries are prudently introducing codes and standards that balance economic growth with environmental sustainance in the long run.

Regulations related to buildings construction have existed since Hammurabi's laws from the 2nd century. For centuries these regulations were focused mainly on fire protection, plumbing, structural integrity and such issues, but not much on energy and water conservation or environmental protection. It's only in the last few decades that the governments have realised the huge potential of building regulation in reducing the high environmental footprint caused by construction and operation of buildings.

The first generation of modern building regulations in US and Europe in the second half of 20th century regulated energy consumption through a few select measures such as air-conditoner efficiency, boiler efficiency and envelope insulation. Largely due to the influence of environmental impact assessment rating systems such BREEAM (1980s) and LEED (1990s) the scope of these regulations is now increasing to cover water, material, indoor environmental quality and site issues as well.

With the exception of China, most developing countries were not actively regulating resource efficiency in buildings till about 15 years ago. Even now, many countries have either not developed their own green building codes, or have not been able to implement them sufficiently. This is noteworthy because majority of new construction globally is now happening in the developing countries. Unlike the gradual development of green building regulations that has happened in the developed countries, developing countrires need to act rapidly to avoid disastrous economic and environmental consequences.

The next section of this document discusses some reasons behind the slow uptake of green building regulations in the developing world, and also possible solutions.

CHALLENGES IN DEVELOPING COUNTRIES

Lack of Political Will and Support

Relevant government and administration support is absolutely crucial for any regulation to be successfully implemented. Typically, code implementation involves several ministraies and departments. Senior government commitment and support helps in eliciting the coordination and cooperation of relevant staff. However, this support should be issue-based rather than personality-based so that senior administration reshuffles or retirements do not affect the code implementation.

In order to gain issue-based support, a strong business case has to be presented, discussed and reiterated so that all team members are convinced about the impact of succesfully implementing the regulations.

Among the benefits that can be included in the business case are economic improvement through preservation of the valuable and limited natural resources, increase in productivity and reduction in national health costs. Governments should present long term impacts of inaction and provide better alternatives. Green buildings should be incorporated as an important tool in the country's climate change mitigation and economic development plan.

Lack of Market Readiness

While local vernacular architecture has a very strong climatic and environmental basis, most new construction developments in developing countries

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has been following the template of modern design from western countries, which is often very inappropriate for the local climate and context. Very few countries have a strong green building movement that is well accepted and understood by the building industry. As a result, the level of awareness and capacity in these countries is low. In such under-prepared markets, rushing in with a code that is very restrictive or complicated may be counter-productive.

While these countries do not have the luxury to wait for the industry to raise their collective green building awareness level, they can start rolling out simple regulations that are in proportion to the maturity of the industry, while working on improvement of market readiness simultaneously.

Once the culture of green building regulation is established in the first few years, more mature regulations could be introduced.

Cost of Building Green

Probably the biggest hurdle to successful green building regulation is the real or perceived increase in construction cost.

In order to dispel this concern, clear cost-benefit analysis should be provided to the building owners. As shown in many countries, a well-planned green building may have a cost premium between 0% to 7%, with paybacks usually between 2 to 5 years.

Incentives from government and preferential financing options from the private sector could further reduce the cost barrier for green buildings.

ALTERNATIVES

The various options that need to be discussed during development of green building regulations are as follows in the next few sub-sections.

Mandatory Codes VS Voluntary Standards

Voluntary standards, such as LEED and BREEAM define the leading edge of sustainable construction, but are used only by a small fraction of the total building stock thus limiting their direct impact on environment and society. Mandatory codes impact a much larger volume and have the potential for a much bigger cumulative impact. A hybrid option, such as Singapore's Green Mark Rating System could be used where the minimum performance level is needed for code compliance and higher levels are needed for the various green ratings.

Prescriptive VS Performance-based Codes

Most national energy efficiency and green building codes are either purely prescriptive, or offer a choice of prescriptive and performance compliance paths. While the prescriptive path is simpler to enforce and evaluate, since it involves complying with some minimum efficiency requirements, such as chiller efficency or glass U-value, they may limit some design flexibility. Performance path is more flexible, but usually requires more analysis and calculation, which may be costly for the building owners.

A hybrid option provides a pallete of measures, and an accompanied tool that could be used to achieve a specific efficiency or saving target using any combination of provided measures.

Energy Efficiency Code VS Green Building Code

In countries where industry maturity or enforcement capacity is limited, the regulation could initially adress only energy and/or water efficiency. Gradually, other green building requirements could be added in subsequent code revisions.

National Code VS Local Code

Depending on the administrative setup of the country, some countries may set their a common national green building code, whereas others may formulate only a national guideline, which could be adopted by the individual provinces or cities for their jurisdictions. Each of these approaches need to tackled slightly differently. A national code should be flexible and appropriate enough to be used in any climatic and geographical location in the country. Whereas a national guideline should be write in such a manner that it could be easily adapted for the local context. It is helpful if some adaptation support is also provided by the national government to the local government units.

New Building Code VS Existing Building Code

Due to the rapid construction growth in most developing countries, it is more urgent to first develop building regulations for new developments. New building codes are easier to implement and also have a much bigger potentaial for savings. In the initial years, if the enforcement capacity is limited, only major renovations in existing building could be required to follow the code. However, once the code becomes commonly accepted, existing building regulations should be rolled out to all existing buildings.

BEST PRACTICES

Based on global experiences in code development and implementation, some important lessons can be learned.

Stakeholder Involvement

Mapping the key stakeholders and engaging them in decision making early on builds consensus and considerably improves chances of implementation success later. Active and persistent engagement with these stakeholders should be maintained to prevent dilution of the code intent and content.

Simplicity of Regulation

Instead of emulating matured policies and sophisticated regulations from developed countries, simplicity should be encouraged. Simplification of the code should be based on prioritisation of measures done through sensitivity and payback analysis. Such simplicity helps owners and design teams in code compliance and the enforcement staff in evaluating.

Incentives

Incentives are great catalysts for green building code implementation. While many governments in the region are reluctant in providing financial incentives, they are more open to non-fiscal incentives such as additional floor area, speedier building permit processing, tax rebates etc. Non-governmental financial incentives in the form of preferential construction loans for developers and green mortgages for owners can also be very efficient ways of increasing code compliance.

Power of Demonstration

Well executed demonstration or pilot projects that act as examples of cost effective code implementation provide the marketing impetus needed to show the feasibility and cost effectiveness of a new regulation.

Long-term Roadmap

Codes that are developed as part of a long-term strategy have a definite focus and are able to lead the market gradually to the high achievement targets set in the plan in a more streamlined manner. Such a roadmap should consider all other avenues of market transformation including education, urban development, tax policies etc. For example, US government has developed a multi-year savings target for building codes that increases energy efficiency savings target from 30% in 2010 to 50% by 2016. It also allocates 0.5% of all carbon emissions allowances amounting to several hundred million dollars per year for code implementation efforts. Singapore Green Building Masterplan targets to 'green' 80% of the country's buildings by 2030.

Supporting Infrastructure

In order for the building sector to be successfully transformed, sufficient support infrastructure needs to be provided. Short-term support could be in the form of user guides, training materials, checklists and tools. In the long-run, setting up building research and education institutes, and a building performance data disclosure system that could be used to develop a performance benchmarking system would be very effective. Setting up a national eco-labelling system for building materials and equipment is also a crucial step in this regard.

A financial system to support new and retrofit green building investments can act as a huge catalyst for green building growth in the market. This was evident in Singapore, which saw a huge spurt in green buildings soon after the cash incentive scheme was introduced.

CONCLUSION

There are several paths to achieving market transformation in the green building sector in developing countries. An appropriate and local relevant solution can be found with sufficient government support and stakeholder engagement.

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A PROPOSED ROADMAP TOWARDS A SUSTAINABLE ECOLOGY OF MODERN LIFE IN TROPICS

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ABSTRACT

Using technologies available today it is possible to create a comprehensive ecological closed-loop cycle of sustainability for a modern society in tropics. This proposed roadmap will demonstrate how zero carbon emission, zero potable water use and zero waste can be achieved without compromising modern day comfort in the tropics.

The success to this roadmap relies heavily on efficiency, recycling and reusing of all waste and green energy production.

The key challenges in this proposed ecological close-loop is efficiency. Thankfully, it has been shown that it is possible to reduce energy consumption by 70% as shown by demonstration buildings in Malaysia. While, in Singapore demonstrated that it is possible to reduce water consumption per capital by 80% as compared to Malaysia. And finally, Curitiba town in Brazil showed that 70% of the city waste can be recycled. These are shining examples showing that "extreme" efficiency is possible.

Much of the energy used in tropical climate is for air-conditioning, where "rejected waste" from this system is condensation water and heat. The condensate water can be treated and reused, while the heat can be used to provide hot water for showers. There is also plenty of rainwater to be harvested in tropical climate and when necessary, it is possible to squeeze water out of the hot and humid climate using free cooling from the night sky. If more water is required, the rejected heat from air-conditioning system can be used to create a chamber of high temperature and humidity where water can condensate easily using ambient temperature and night sky cooling.

The rejected waste from water use from showering and washing is then used for irrigations and toilet flushing, into black water. Methane can be harvested from black water through anaerobic digestion process. In fact, all organic waste can be digested into methane, fertilizer and waste water. The methane produced is then use to power a tri-generation system that provide electricity and chilled water for buildings. The wasted CO_2 from burning methane is then distributed into algae farm together with the processed organic waste water as nutrient. It is also possible to use nickel nanoparticles as a catalyst to convert CO_2 produced into calcium carbonate, a key ingredient for cement.

A simple roadmap with flow-chart diagram was created from the combination of various technologies to demonstrate *a* potential path towards a sustianable ecology of modern life in tropics.

INTRODUCTION

A sustainable earth is only achievable when the occupant of this planet has developed ways to live life in this planet without further negative impact to the environment. The objective of this paper is to describe one possible roadmap forward for the tropical climate communities to achieve net zero carbon emission, zero water and zero waste using proven technologies that are known today.

This paper addresses energy efficiency in buildings, green energy production, green transportation, water efficiency, waste water collection & recycling and solid waste disposal methodology and how integration of various sectors of technologies is possible to provide a complete cycle of sustainability in a tropical climate community.

Energy Efficiency in Buildings

Over the past 10 years, several low energy buildings in tropical climate have been demonstrated to have building energy index of 100 kWh/m².year and lower, without considering the use of renewable energy in these buildings. Both the Energy Commission's "Diamond" building in Putrajaya, Malaysia and the Malaysian Green Technology Center's "Green Energy Office (GEO)" building in Bangi, has a measured energy index of 65 kWh/m².year, without accounting for the installed renewable energy in these buildings. In comparison, typical buildings energy index in Malaysia range from 150 to 200 kWh/m².year.

These buildings are demonstration that when buildings are designed well, extreme low energy use in building is possible.

The following are the key main features in these buildings:

1. Daylight Harvesting. GEO is operating with 100% daylight harvesting for all occupied spaces, while Diamond is operating with more than 50% of its occupied spaces with daylight harvesting.

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2. Efficient Electrical Lighting. Although much of the building is daylight, the electrical lighting power density is these buildings are as low as 4.8 W/m².
3. Efficient Small Power. The use of low power consumption computers such as notebooks are highly encouraged in these buildings. The measured small power consumption in these buildings were as low as 5 W/m².
4. Air Tightness. Particular attention to building air-tightness was implemented in these projects. It was identified very early in the design stage of these buildings that infiltration of outside air into building is very energy inefficient for the building.
5. Efficient Air-Conditioning System. Both buildings utilise chilled floor slab as a radiant cooling technology. This technology allowed the air-conditioning system to be designed separately for sensible heat and latent heat gain in building. The advantage gained from such a system is that a more efficient system can be used for sensible heat gain removal, while another system is used to optimise latent heat gain removal from a building. The fan power used in these buildings is very low because it is sized to remove latent heat, while most of the sensible heat will be removed via the chilled floor slab. It is also possible to replace the chilled floor slab with chilled beam technology to achieve similar results.

Although these buildings demonstrated very low building energy index, there are still much that can be improved. For example, the air-conditioning system in the GEO is operating at a significantly low System Coefficient of Performance (COP) compared to typical buildings, while the Diamond building is utilizing a district cooling system, where it is not possible to make any further improvement. Based on the contractual requirement, a fixed system COP of 4.2 was assumed for the district cooling system to compute the building energy index for the Diamond building. In short, it would still be possible to reduce these buildings energy index even further, if the air-conditioning system was improved.

Furthermore, the availability of technologies such as liquid desiccant system in this region offer further opportunities to remove latent load from building utilising free energy from waste heat from a building.

An energy simulation study indicates that it is possible to reduce these building energy index below 50 kWh/m².year if further improvements were made to the air-conditioning system.

In summary, these demonstration buildings displayed that it is possible to drive energy efficiency in building to extreme when the building is addressed holistically.

It is also very important to note that energy efficiency in building is addressed as the most important item in the cycle of sustainability, because it is not financially sensible option to produce enough renewable energy for a building that is wasting energy.

Tri-Generation System

Tri-generation is a common technology where fuel is used to generate electricity, chilled water and hot water at the same time.

Such a system utilizes raw fuel such as gas or oil for the generation of electricity (via boiling water for steam powered micro-turbine or through fuel cell); where the wasted heat from the generation of electricity is then used for generating chill water for cooling purpose with an absorption chiller and finally the waste heat from the absorption chiller is used to provide hot water to residential apartment or hotels. This type of utilization of the gas increases the efficiency of the gas to approximately 90% efficiency. Where else, in a typical power plant it will only convert approximately 35% of the gas energy into electricity and the waste heat is dumped into the river or sea.

For the purpose of this paper, a small tri-generation plant is conservatively assumed to produce 30% of the fuel heat into electricity generation, 55% into hot water that powers an adsorption chiller with a coefficient of performance (COP) of 0.8, i.e. converting 44% of the heat content in the fuel into useful chilled water for cooling purpose.

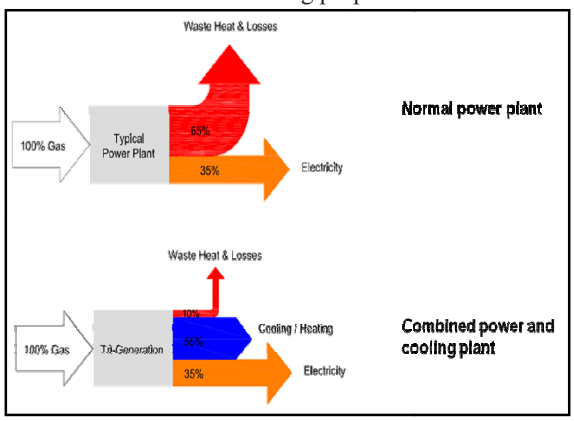


Figure 1 Co-generation System Efficiency

Renewable Energy

In a tropical climate, there are three (3) types of technology of renewable energy that can be easily implemented in buildings. These are:

1. Photovoltaic. In a tropical climate, 1 kWp of photovoltaic produces a minimum of 1100 kWh per year. Considering a typical

crystalline photovoltaic system, the roof space required is approximately 8.5 m² for 1 kWp. This will work out to approximately producing 130 kWh/m².year of roof space. This amount of energy produced is adequate to power a 3-storey building with energy index of 43 kWh/m².year or a 2-storey building with energy index of 75 kWh/m².year, assuming that the floor area is the same on every floor. Based on current photovoltaic efficiency, it will not be adequate to power a high-rise building.

2. Biogas from organic waste. The high temperature we have in a tropical climate is ideal to generate biogas from organic waste through anaerobic digestion process. The produced biogas would be used by the tri-generation system to generate electricity, chilled water for air-conditioning and hot water for domestic use. From the blackwater, it is possible to generate about 13.3 kWh/person per year of electricity and 19.5 kWh/person chilled water per year using a tri-generation system. In addition, assuming that if one person generates 100 gram of food waste per day, the amount of biogas generated from this is approximately 14.2 kWh/person per year of electricity and 20.8 kWh/person per year of chilled water using a tri-generation system. This provided a combined yield of 27.5 kWh/person per year of electricity and 40.4 kWh/person per year of chilled water from organic waste.
3. MicroAlgae. In a tropical climate, due to the amount of solar radiation received, it is ideal for planting microalgae that can be harvested for energy easily. Biodiesel is then produced from microalgae and it is used to power tri-generation plant or bio-diesel vehicles. On a low yield scenario, microalgae would produce approximately 10 times more biofuel than palm oil per m² of area used. On a high yield scenario, biofuel from microalgae increased to 18 times more than what palm oil can produce. Planting microalgae in a photobioreactor tube on façade of a building will produce approximately 78.8 kWh/year per m² of planted area of electricity and 115.6 kWh/year per m² of planted area of chilled water. In addition, locating a tri-generation plant that produces CO_2 close to a microalgae plantation is also very beneficial because the CO_2 can be routed into the microalgae plant to boost up the growth rate of microalgae while reducing CO_2 emission to the atmosphere, producing higher yield of electricity and chilled water.

Zero Potable Water

Zero potable water use can be achieved with the following technologies in tropical climate zone:

1. Water Efficient Fittings,
2. Rain Water Harvesting,
3. Air-Conditioning Condensate Water Recovery and
4. Water from the humid air:

Efficient use of raw resource is always a prerequisite for any attempt at a truly sustainable society. Therefore, the first priority towards zero potable water use is efficient fittings, cloth washer and dishwasher. Led by countries like Singapore, it has been shown that it is possible to use as little as 152 litres of water per person per day or 55.3 m^3 of water per year per person. However, this is still a high figure compared to UN recommendation. The UN suggested that each person requires only 20-50 litres of water per day for drinking, cooking and sanitation need. This translates to 7.3-18.2 m^3 of water requirement per person per year.

It is also important to note that the efficient use of water include ensuring that all grey water are reused without requiring any treatment for irrigation, toilet flushing and with minimal filtration be used by the cooling tower of air-conditioning system.

The sum of average annual rainfall in Malaysia is approximately 2,500mm or a capacity of 2.5 m^3 of rainwater per m² of roof area per year. Assuming that all the rainwater is captured to be used, a minimum rainfall catchment area of 3 m² is required to be provided to ensure adequate water is provided for each person.

The longest period without rain was measured to be 29 days based on the daily rainfall data from the Department of Irrigation and Drainage (DID) Ampang, Malaysia for the years of 1983 to 1997. This data also showed that an average long period without rain is 15 days.

In addition, air-conditioning in tropical climate will also provide a significant amount of condensate water due to the high latent load of this climate zone. The condensate water should be retrieved as part of the rainwater harvested. The outdoor air moisture content is almost constant in tropical climate, at 19~20 grams/kg of air. While the indoor air-conditioned space moisture content range from 10~12 grams/kg of air. This will provide approximately 7 grams of water that is removed from the fresh air supplied for each kg of fresh air provided. The fresh air requirement in an office space is approximately 0.55 l/s per m² of space based on Ashrae 62.1, for an occupant density of 10 m²/person. This will yield 0.045 m³/year of water per m² of office space, or 0.45 m³/year per person in the office space.

Furthermore, in a hot and humid tropical climate, it is easy to squeeze water from the air. The typical dew point temperature of outdoor air in a tropical climate is 22~24°C. As long as any surface is brought below the dew point temperature, condensate water will be formed. With the average night time effective sky temperature in tropical climate of 15°C, it is possible to design roof system with a minimum of 30° tilt angle to collect dew water from the roof throughout the night. The student-designed "Chaac Ha" water collector can harvest 2.5 liters of drinking water from dew each night from an inverted umbrella of approximately 3-meter in diameter in a hot and humid tropical climate of Yucatan, south Mexico. This will provide around 0.13 m^3 of dew water per year per m^2 of roof space.

Finally, there is an option to squeeze even more water from the air of tropical climate by condensing it out of the air using excess renewable energy produced. This will only be done during long period of dry season when the rainwater tank has dried up.

Water treatment technologies

Recovered rainwater and condensate water can be treated locally using many available technologies such as bio-sand filtration, coupled with UV light or ozone treatment to sanitize the water.

The first household biosand filter was conceptualized by Dr. David Manz in the late 1980s in Canada. It is a simple, low-cost device conceived to address water and sanitation problem for the poor and it is ideal to treat water from surface runoff such as rainwater and condensate water harvesting. It has been estimated that more than 200,000 biosand filters are in use throughout the world today.

Although the use of bio-sand filter would provide potable water that is already safe for consumption, additional UV or Ozone treatment system may be further applied to ensure that the water is truly safe for human consumption.

Zero Waste

The town of Curitiba in Brazil has a recycling rate of 70% of their waste today. In addition, they have a target of zero waste in the city within the next 10 years. This indicates that the target of zero waste is achievable in practise.

Waste such as glass, papers, plastics and metals are all recyclable. The leftover of these dry recyclable items are organic waste such as food waste and black water.

As mentioned in the renewable energy section, all organic waste such as food waste and black water are collected for bio-gasification and use it to produce renewable energy, chilled water and hot water for domestic use.

The by-product of bio-gasification of food waste and black water is water and fertilisers. The water derived from such anaerobic process will still have bio-nutrient that can be fed to the microalgae in the photobioreactor tube. The fertilisers from the anaerobic process is then use by the urban farms to increase sustainable food production for the society.

Test Case Scenario

Based on all the technology mentioned in the prior section, a test scenario was made to put these theories to test.

A 10-storey office building, with occupant density of 10 m^2/person is assumed. The building is rectangular with width and length of 35m x 55m and has a floor to floor height of 4m. It is also assumed that this building has the efficiency index of 65 kWh/m^2.year (matching the two existing demonstration office building in Malaysia). From the demonstration buildings, the split between the electricity and cooling energy is approximately 65:35, providing a requirement of 42.3 kwh/m^2.year of electricity and 125 kWh/m^2.year of cooling energy (assuming a system coefficient of performance of 5.5).

Based on the occupant density, the population of the building will be 1925 persons. These populations are assumed to be living in a double storey house with roof area 90m^2 each. Each of building population is then assumed to have an average household size of 3.5 persons per household. Finally, an energy efficient household energy consumption per year was estimated to be 2600 kWh/year in 2005 by Integrated Resources Planning report for Malaysia.

The total population of 1925 households with an average household size of 3.5 persons is 6738 persons. Using the higher end of water requirement per person of 50 litres per person per day of the UN recommendation, a total of 122,600 m^3 of water is required per year for this population density.

Renewable Energy Possibility

1. Photovoltaic on the roof. The office building roof area of 1925 m^2 will provide 13.8 kWh/m^2.year for the office building. While an installation of a 2.5 kWpeak photovoltaic on the roof of residential houses (taking up only 30% of the residential roof space) will provide adequate electricity to power the energy need of an efficient household.
2. Black water from the 1925 household of 3.5 persons average size, will contribute to 4.7 kWh/m^2.year of electricity and 6.8 kWh/m^2.year of cooling energy from a tri-generation for the office building.
3. Assuming a food waste of 600 grams per person per day for Malaysian population (The Star newspaper, 5 June 2013), this will yield 29.8 kWh/m^2.year of electricity and

43.7 kWh/m².year of cooling energy from a tri-generation for the office building.

4. Assuming that microalgae are planted on 50% the building façade. On a low yield scenario, it will produce 14.8 kWh/m².year of electricity and 21.6 kWh/m².year of cooling energy from a tri-generation for the office building.

The energy efficient office building needs to have 42.3 kwh/m².year of electricity and 125 kWh/m².year of cooling energy.

The first three items on renewable energy produced 48.3 kWh/m².year, exceeding the office building need without the use of renewable energy from microalgae. However, it only produced 54.1 kWh/m².year of cooling energy, short of 71 kWh/m2.year of cooling energy. From the microalgae, an additional 21.6 kWh/m².year of cooling energy is attainable and yet it is still short of 49 kWh/m².year of cooling energy for the offices.

However, when all four renewable source is accounted for, the electricity produced exceeds the building need by 20.8 kwh/m².year. Assuming a conventional compressor driven Chiller system coefficient of performance of 5.0, this will provide 104 kWh/m².year of cooling energy requirement, exceeding the building cooling requirement by 55 kWh/m².year of cooling energy.

In other words, this system will have an over production of 10 kWh/m².year of excess energy to power the grid or electric vehicles for the occupants of this site.

Moreover, the CO_2 gas produced by the tri-generation system will be used by the microalgae system, creating a closed cycle of sustainability for a society in tropical climate.

Water Harvesting Possibility

1. Rainwater harvesting from roof. The total roof area of 1925 houses will provide a total of 433,000 m³ of rain water harvesting per year. This is 3.5 times the water requirement of the population.
2. An office population density of 1925 will provide 866 m³/year of condensate water.
3. Dew water collection from roof. The total roof area of 1925 houses of 90 m² per unit will provide a total of 22,500 m³/year of dew water.

The total potential water harvested from this test case scenario is 456,500 m³/year. This is 3.7 times more than the projected need of 122,600 m³/year for this test case population. A significant amount of it is from rainwater. This indicates that it is very important to size the rainwater-harvesting tank carefully to ensure that it is adequate to provide the amount of water required by the occupants for daily use even during a prolonged dry period of 29 days.

Zero Waste

Zero waste is a matter of society responsibility. All the dry waste are recyclable, while all wet waste from food production and black water are harvested for its energy.

CONCLUSION

It is shown in this paper of one potential roadmap towards a society that has zero carbon emission, zero potable water consumption and zero waste.

It should also be highlighted that there are many new emerging technologies are not even considered yet in this paper. One such technology is carbon capturing from a tri-generation plant to produce cement using nano nickel particles as a catalyst to mimic seashells on the ocean floors to produce calcium carbonate (a key ingredient for cement). Another worthy technology is water capturing from exhaust of cooling tower by running water pipes at ground temperature through it.

The development of these new technologies will eventually make the route to a truly sustainable society much easier and at a lower cost.

It is proposed herewith that an attempt should be made now to demonstrate these possibilities because there is much to learn from the implementation of these various technologies in an integrated manner. More importantly all the technology mentioned in this paper are ready to be implementable today in any project.

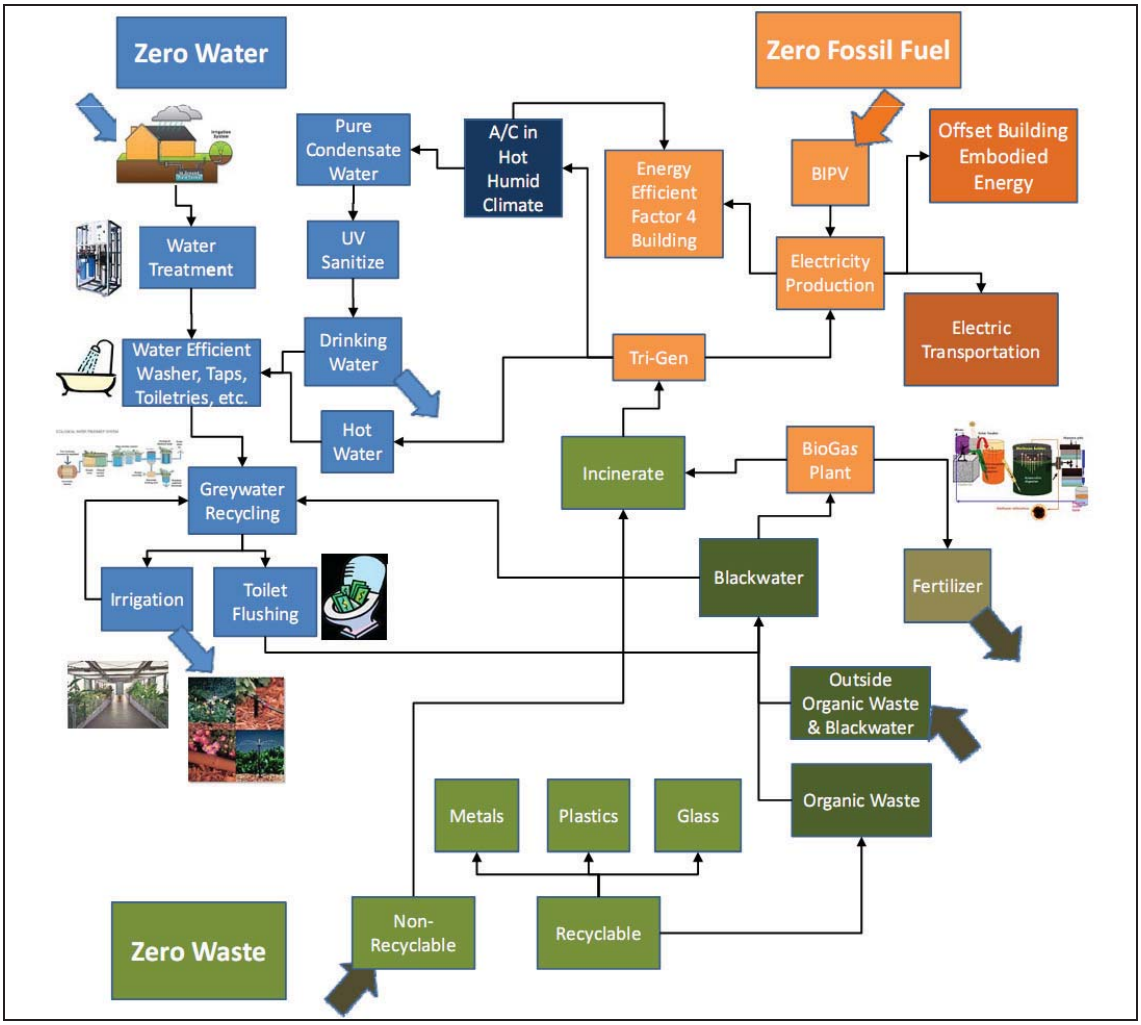
It is also noteworthy that these technologies are available today because each of these technologies is already a financially feasible solution to be implemented.

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Figure 2 A Proposed Roadmap towards a Sustainable Ecology of Modern Life in Tropics



DEVELOPMENT OF JKR/BSEEP TECHNICAL PASSIVE DESIGN GUIDELINES FOR MALAYSIAN BUILDING INDUSTRY

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ABSTRACT

The JKR-UNDP's Building Sector Energy Efficiency Project (BSEEP) in Malaysia was aimed at reducing the growth rate of GHG emission of the building industry in Malaysia. Component 4 task in BSEEP in 2012 is to develop a Technical Design Guideline for Malaysia. This technical guideline is required to be made relevant to the building industry, addressing immediate concerns by building design professionals, providing adequate technical knowhow and providing option for financial saving estimate, while at the same time keeping the guideline simple to read, understand and use.

A stakeholder dialog session was made at the start of the project and it provided the basis on the issues that should be addressed by the proposed Passive Design Guidelines. The following chapters were developed:

Chapter 1 – Fundamentals: addressing compounded advantage to optimize the whole building, the 1st law of thermodynamics, heat transfer and thermal comfort.

Chapter 2 – Malaysia's Weather Data: provides an understanding of local climatic values on the air properties, solar radiation, wind conditions, effective sky temperature and etc. It also provides recommendations on the passive design possibilities based on each climatic property presented.

Chapter 3 – Building Form, Orientation and Core Location: addresses the impact of 18 different building forms, orientations and core locations on the energy efficiency of a building.

Chapter 4 – Daylight Harvesting: provides daylight harvesting potential specifically for tropical climate.

Chapter 5 – Glazing Properties: addresses the technical selection criteria on glazing for tropical climate.

Chapter 6 – External and Internal Shades: provides the amount of energy saved from the use of external and internal shades on various façade orientations.

Chapter 7 – Wall Insulation: provides the amount of energy saved from the use of wall insulation and effect of internal night load in tropical climate.

Chapter 8 – Roof Insulation: provides the amount of energy saved from roof insulation and effect of different air-conditioning hours in tropical climate.

Chapter 9 – Atrium Ventilation: provides 11 different atrium ventilation strategies and its impact on energy efficiency.

Chapter 10 – Zoning and Infiltration: provides the impact on energy efficiency due to location of 24 hours air-conditioned zone in an office building scenario and air leakage rating based on Malaysian climate.

INTRODUCTION

This Energy Efficiency Passive Design Technical Guideline was written specifically for Malaysian climate zone. It is an attempt to provide a simple and yet useful guideline to practicing building designers in Malaysia for design decision to be made quickly for the promotion of energy efficiency in building.

An industry dialog was carried out on the 13th June 2012 to gain an understanding on the status of current energy efficiency design practices and to identify the information that is sought by the industry, for energy efficiency to be practiced on new building development. 18 industry leaders from both private and public sectors attended the dialog session.

A "wish list" of information requested by the industry was created from the industry dialog session. From the "wish list", sets of building energy simulation studies (using climate weather data of Malaysia) were developed and conducted to provide the foundation for the recommendations made in the guideline.

Due to limited time to produce the guideline, only one building model was developed to derive all the estimated energy reduction. Different building size, shape and model will yield slightly different results. However, the results and recommendations from this document is deem accurate enough as a general guide to make an informed building design decision quickly in the interest of energy efficiency in building. The default building model used for the studies was based on a hypothetical office building scenario of 17 floors with a floor utilization efficiency of 78% and a gross floor area (GFA) of 38,403 m².

CHAPTER 1 - Fundamentals

This chapter addresses the key fundamentals in energy efficiency in building. These are:

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1. Energy efficiency in building can only be achieved by addressing the whole building holistically. I.e. it is impossible to have more than 50% energy reduction in building by addressing 1 or 2 features in a building, however if 50 or more features are addressed, it is possible to have an energy reduction of 50% or more.
2. The 1st Law of Thermodynamic was explained in this chapter within a building scenario to establish a sense of energy flow in building for practising architects and engineers to understand that energy cannot just disappear from a building.
3. Various types of air properties, such as dry, wet and dew point air temperature, differences between relative humidity and moisture content in air were also explained in this chapter.
4. Various types of heat transfer mechanism of conduction, convection, radiation and phase change was also addressed in this chapter.
5. The important thermal comfort parameters such as operative temperature, Fanger's comfort model and adaptive thermal comfort model was also presented in this chapter.

These fundamentals were important to be established within the 1st chapter for this UNDP-JKR technical guideline because all the other chapters will reference these basic fundamentals of building science.

CHAPTER 2 – Weather Data

A clear understanding of Malaysia's weather data enables designer to design building that response to the climate instead of against it. The climate in Malaysia is fairly consistent daily over the entire year; therefore it is useful to get an overview of an average day of hourly performance and the maximum and minimum hourly weather data for a full year.

This chapter provided information on dry bulb temperature, wet bulb temperature, relative humidity, humidity ratio (moisture content), dew point temperature, global radiation, direct radiation, diffuse radiation, cloud cover and wind speed & direction, effective sky temperature and ground temperature of Malaysian climate. The energy efficiency opportunities and risk offered by the climate is also presented in this chapter.

Many charts were provided in the guideline for ease of understanding the data and table of raw data is provided for users who wish to make further use of these data for more in-depth analysis on their own.

CHAPTER 3 – Building Form, Orientation and Core Location

Every architect was taught about important of building orientation in terms of energy efficiency. However, the evaluation of building orientation cannot be made without including the building form and core location because these items have a significant influence on the overall energy efficiency of a building.

The selection of building form often dictates where the core location can be placed, while the core location dictates whether mechanical system is used to ventilate spaces such as toilets. Moreover, it is also possible to place core location as a buffer zone to reduce the impact of solar radiation on the air-conditioned space of a building. The selection of core location would than dictates the main orientation of the building that exposes air-conditioned spaces to direct solar heat gain.

In addition to solar heat gain, exposing façade to a particular orientation may also increase infiltration rate due to the exposure to higher wind velocities.

Chapter 3 takes these factors into considerations and provides a simple guidance on the impact of building form, core location and orientation to allows designers understand the influence of their decision at an early stage of building design

It was shown in this chapter that the worst building form has an energy consumption 7% higher than the best building form in terms of energy efficiency.

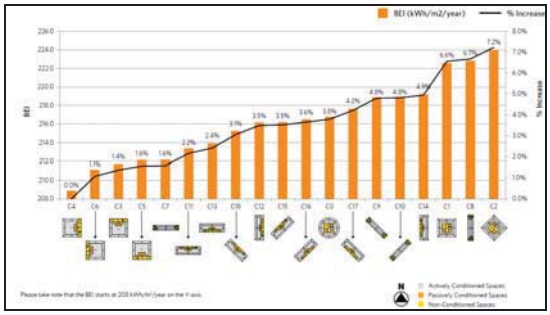


Figure 1 Chapter 3, Building Energy Index of Different Building Form, Orientation and Core Location based on Malaysian Climate Zone.

CHAPTER 4 – Daylight Harvesting

Daylight harvesting in building may seem to be a very simple task but it is a subject that need to be mastered well in order to be implemented successfully in this climate zone. There are many design issues that need to be addressed adequately. An attempt is made in this chapter to address all the key issues related to daylight harvesting within the context of Malaysian climate.

The tropical Malaysian climate is ideal for daylight harvesting to be practiced in office buildings because daylight is consistently available daily from the hours of 8am to 6pm. Since Malaysia is located near the equator, there is hardly any variability of season that changes the daily availability of daylight.

Acclimatization of Daylight Factor to Malaysia was made in this guideline, showing that a daylight factor of 0.5% will yield more than 90% of the hours of

9am to 5pm more than 100 lux level from diffuse radiation alone.

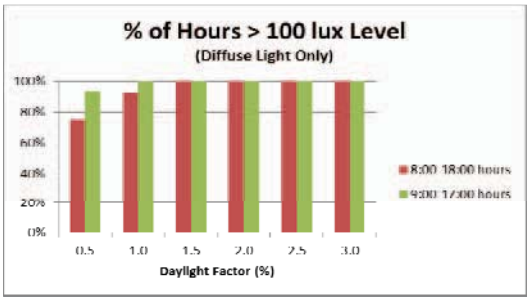


Figure 2 Chapter 4 Daylight Factor Acclimatisation to Malaysian Climate, Graphs shows the percentage hours in a year exceeding 100 lux level from the daytime hours of 8am to 6pm and 9am to 5pm at various Daylight Factors.

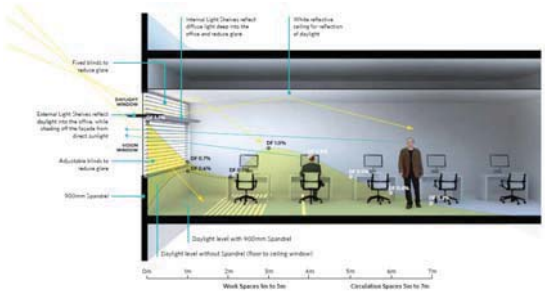


Figure 3 Chapter 4 Classic Daylight Harvesting Strategy from Façade showing a split window design for daylight and vision window, incorporating light shelves and glare protection blinds.

For a good quality daylight harvesting strategy to be implemented in tropical climate, the following design principles have to be addressed:

- solar heat gain minimisation,
- glare protection,
- deep daylight penetration and
- uniform daylight distribution.

Each of the design principle above is discussed in details in the guideline and examples provided. In addition, various charts were also provided in this chapter for quick estimation of depth of daylight penetration from a basic implementation of daylight harvesting system using horizontal venetian blinds.

CHAPTER 5 – Glazing Properties

The selection of correct glazing properties can help to increase energy efficiency in the building and yet provide the 'desired look' of the building. Right glazing selection can reduce the cooling load in building, provides better comfort while allowing smaller air-conditioning system to be used, saving investment cost. In addition, selection of right glazing also influences the potential of daylight harvesting in building that will reduce electrical light usage that saves a significant amount of energy in building, as well as providing an improved thermal comfort and visual comfort environment to the building occupants.

Finally, many architects today understood the need to have low solar heat gain coefficient (SHGC) to reduce heat gain in building and high visible light transmission (VLT) to promote daylight harvesting. However, not many understood the relationship between SHGC and VLT due to different glazing technology and mechanism used. This, among many issues with regards to glazing properties selection, is addressed in this chapter.

The ratio of VLT over SHGC provides a term called light to solar gain ratio (LSG). Single glazing **without** low-e properties has LSG values of 0.5 to 1.0 depending on the colour of the glazing. Single glazing **with** low-e properties has typical LSG values of 1.05 to 1.25. High performance, double glazing with low-e properties has typical LSG values of 1.6 to 2.0.

It is recommended not to use double glazing with LSG values less than 1.5, because the marginal cost of having double glazing with LSG value above 1.5 is relatively low once double glazing is selected to be used in the first place.

CHAPTER 6 – External and Internal Shading

The use of external shades has been well promoted by many architectural books as essential solution to energy efficiency and thermal comfort in tropical climate. Meanwhile, improvement in glazing technologies (Chapter 5) has enable buildings to be built today without the use of external shading devices while complying with respective countries energy code. In addition, there exist internal shading devices in the market that claims to reduce solar heat gain in building by 80% or more. Is it beneficial to combined all these technologies together and how should this combination be made to optimize the efficiency for the building is addressed in this chapter.

The total SHGC of any fenestration system can be estimated using the following equations:

$$SHGC_{total} = SHGC_{ext} \times SHGC_{glz} \times SHGC_{int}$$

Where,

$SHGC_{total}$; is the Solar Heat Gain Coefficient of the entire fenestration unit.

$SHGC_{ext}$; is the Solar Heat Gain Coefficient of external shading devices (1, if no external shading device is used)

$SHGC_{glz}$; is the Solar Heat Gain Coefficient of the glazing.

$SHGC_{int}$; is the Solar Heat Gain Coefficient of internal shading devices (1, if no internal shading devices is used)

Table 1 below, provides an indication of the potential SHGC total based on various possible combination of external shades, glazing properties and internal shades. A SHGC reduction of approximately 90%

was shown to be possible from a base case of a clear glazing to a case where a good external shade, glazing properties and internal shade are used.

Table 1
SHGC Total computed from various combinations

Descriptions	SHGC ext shades	SHGC glazing	SHGC int shades	Computed SHGC total
Poorly designed façade	1.00	0.87	1.00	**0.87**
Only 1 item done well	1.00	0.30	1.00	**0.30**
Only 1 item done well	1.00	0.87	0.30	**0.26**
Two (2) items done moderately well	0.70	0.50	1.00	**0.35**
All 3 items done moderately well	0.70	0.50	0.70	**0.25**
All 3 items done well	0.50	0.30	0.50	**0.08**

CHAPTER 7 – Wall Insulation

Energy simulation was conducted to derive an approximate estimate of energy and peak load reduction of insulated wall. These estimates are provided as a guide for quick design checks by architects, engineers and building owners to estimate the cost saving of implementing these energy efficiency features. The simulation study model was based on Chapter 3, Case 1 of a Square Building, without any external shades. Case 1 study model is almost a replica of the building model used by the Deringer Group, Berkeley, California, to derived the OTTV constants for all type of buildings for Malaysia, Singapore, Indonesia, Phillipine and Thailand, under the ASEAN-USAID program in the 1980s - 1992. The only differences is that the current model building size, floor efficiency and operating assumptions were updated to current standard of practise. The OTTV formulation is still in use today and deemed to be accurate on all types of buidings use, shape, size and hours of operation in these countries.

The energy saved due to the use of insulated wall is dependent on the internal heat load during night time (night time parasitic load). Three (3) scenarios were created where the small power (equipment) night time parasitic load is set to 50% (high night time parasitic load), 35% (mid night time parasitic load) and 10% (low night time parasitic load). A "Wall Simplified Energy Index" is created for the ease of computing the energy reduction provided by wall insulation. The creation of the wall simplified energy index is to provide an easy method to estimate energy reduction due to wall U-value selection in Malaysian climate zone and should not be used for any other purpose.

Table 2 below is a sample output of insulated wall scenario based on a medium night time parasitic load. This table can be used to compute approximate energy reduction and peak load reduction due to the use of wall insulation.

Table 2
Energy and Peak Load Impact of Wall Insulation (medium night time parasitic load scenario)

Descriptions	Ashrae U-value ($W/m^2 K$)	Wall Simplified Energy Index (kWh/year of m^2 of wall area)	Peak Cooling Load Index (ton/m^2 wall)
Steel Sheet, 10mm	6.68	55	0.476
Concrete Wall, 100mm	3.40	32	0.457
Brick Wall, 115mm	2.82	30	0.456
Double Brick Wall with 50mm cavity, 300mm	1.42	25	0.452
Autoclave Lightweight Concrete, 100mm	1.25	24	0.450
Autoclave Lightweight Concrete, 200mm	0.75	22	0.449

CHAPTER 8 – Roof Insulation

There are many different types of roofing systems in use in Malaysia. The three most commonly practiced roofing systems are: concrete flat roof, light-weight pitched roof and light-weight pitched roof over concrete flat roof. The energy efficiency behavior of insulation provided on these roof systems is slightly different for each type of roof system and is particularly affected by the different hours of air-conditioning operating hours in the space immediately below the roof.

A typical roof is fully exposed to the entire sky dome and is strongly influence by the received solar radiation and the effective sky temperature. During daytime, radiation heat transfer on the roof is both being received and reflected at the same time. The sun (solar radiation) is heating up the external roof surface, while the rest of the sky dome (effective sky temperature during daytime averaging around 20°C) is cooling the external roof surface. The net radiation gain on the roof during daytime will be positive due to significantly higher radiation heat transfer from the

sun and the hot external roof surface will transmit heat into the building via conduction through the roof. Insulation of the roof in this case will reduce the heat that is transmitted into the building, reducing the building cooling load.

However, during night time, where there is no solar radiation heat gain and the average effective sky temperature is 15°C (Chapter 2), heat is removed from the roof surface into the sky via radiation heat transfer mechanism. Warm temperature from the internal building space below the roof is conducted to the top surface of the roof and rejected to the cold night sky. The provision of insulations in roof reduces the amount of heat that is rejected out of the roof during night time. Depending on the hours of operating the air-conditioning system, the provision of insulation in roofing system can be beneficial or detrimental to the energy efficiency of the building.

Energy simulation was conducted and tables were provided in this chapter to allow user of the guideline to select the insulation appropriate for the building usage.

Table 3 below is a sample output for flat roof with air-conditioning hours of 8am to 5:30pm scenario. The Ringgit Malaysia saved per m² of roof area is provided to allow user of the guideline to make quick payback analysis based on current electricity tariff in Malaysia.

Table 3
Energy Reduction of Flat Roof Insulation
Air-Conditioning Hours: 8am to 5:30pm

Flat Roof Insulation (mm)	Energy Used kWh/m² of roof area per year	RM/m² reduction per year
0	135.06	
25	124.19	3.80
50	122.95	4.24
75	122.42	4.42
100	122.12	4.53
200	121.63	4.70
300	121.63	4.70
400	121.42	4.77
500	121.39	4.78

CHAPTER 9 – Atrium Ventilation Strategy

It is commonly considered that natural ventilation in atrium spaces is an energy efficient feature in buildings. However, if the atrium space is surrounded by air-conditioned space, the exposure of the atrium space to outdoor air will introduce more surface area of the building to be in contact with outdoor air temperature and humidity. This type of exposure increases the risk of conduction heat and air leakages into the air-conditioned spaces increasing building energy consumption. At the same time, the possibility of air leakages between the conditioned office spaces into the atrium space due to cracks surrounding the partitioned windows (or worse, open windows) will help to cool the ground floor of the atrium space because cold and dry air is heavier than hot and humid air and will drop to the bottom of the atrium space. However, if natural ventilation is practiced for the atrium space, these cold air leakages from the office will be blown away without providing much benefit to the occupants at the atrium space.

Building simulation study was conducted on 10 different options on the atrium ventilation strategies.

It was found from the studies that it was not possible provide comfort condition at all time if an atrium space is naturally ventilated. At best, comfort condition up to 66% of the typical working hours is achievable using a combination of natural ventilation and doors/roofs opening hours in the atrium space to provide building energy reduction up to 3.3%.

It was also found that building energy reduction up to 1% is possible for an air-conditioned atrium scenario when it is naturally ventilated at night. The colder outdoor air during night time cooled the building structure down causing it to use less energy to cool the atrium space during daytime.

CHAPTER 10 – Zoning and Infiltration Control

Zoning

It is known that there are practicing architects that practices energy efficiency zoning in buildings by locating rooms according to the flow of leakages of air-conditioned air from the coldest room towards the warmest room. This will ensure that leakages of cold air from the coldest room will benefits other spaces before the leakages of cold air is allowed to escape out of the building. This assumption is tested in this chapter and the energy saving potential from such an implementation is also provided in this chapter.

The result of the study indicates that this is indeed a good design practise. Having 24 hours air-conditioned spaces surrounded by 8 hours air-conditioned spaces saves up to 2% energy per floor. The result of the study aslo indicates that if 24 hours air-conditioned spaces are required to be located on the façade, energy lost can be significantly minimised by ensuring that minimum glazing are used.

Infiltration

Infiltration of outdoor air into air-conditioned spaces has significant impact on energy efficiency and indoor environmental quality in building. In Malaysian climate, infiltration introduces both sensible and latent (moisture) heat into building. The latent heat (moisture) presents a larger problem for the building because not only does moisture requires significant amount of energy to be removed by the air-conditioning system, excessive moisture gained

also lead to a higher risk of molds growth in the building.

Eight (8) simulation cases were developed to study the impact of infiltration in building, ranging from one open main door, up to 1.6% windows are opened and finally various crack flow coefficient of window perimeters. It was found with the test model that up to 12% energy saving was possible by minimising infiltration on these various parameters. The financial payback study was also provided for improving crack flow coefficient of window perimeters.

CHAPTER 11 – Interior Layout of Offices

Interior layout of office space influences energy efficiency in building predominantly due to the effect of maximizing the benefit of daylight harvesting.

Individual rooms in offices are normally allocated to higher ranking (senior) staffs. These higher ranked staffs are typically busy people that attend a lot of meetings and conferences, spending much of the time not in their own office room. In addition, it is also common to allocate the best daylight spaces for higher ranking staff. This type of interior layout will then cause daylight to be provided to unoccupied rooms, while at the same time electrical lights are switched on for open space offices that are typically located away from daylight spaces.

An energy efficient design alternative is to switch the position of open space offices with the individual offices. This will then ensure that daylight are provided to predominantly occupied open space offices, while individual offices will have its electrical lights switched off when it is not in use.

This simulation study was made assuming that it is possible for individual office spaces to be fully daylight when it is located next to the façade.

Table 4
Energy Reduction of Moving Regularly Unoccupied Rooms Away from Daylight Area

% working hour individual offices will be empty.	Saving kWh/m² per year of moved individual offices.	RM Saved Per Year Per m² of moved individual offices.
50%	12.6	4.40
30%	7.4	2.60
10%	2.8	0.98

Table 4 is the key output of Chapter 11, which showed that the energy saved is only RM 4.40 per year per m² of individual office space moved. Assuming that each person is only takes up 10m² of space, for each person moved, it would reduce energy use in building by RM 44 per year per person if this strategy is implemented.

CONCLUSION

The Passive Design Energy Efficiency Technical Guideline for Malaysia is intended to provide to the Malaysian building industry a simple and unambiguous guideline on energy efficiency in tropical climate building. A host of simulation studies were made by the Component 4 team of the UNDP-JKR, BSEEP project to provide an approximate estimate of energy reduction potential of each passive feature in building. These energy reductions potential can be used to compute payback studies and internal rate of return based on the investment cost to be made for each of these feature on a building.

ACKNOWLEDGMENT

Christopher Barry of Pilkington for his contribution to Chapter 5 on Glazing Properties, which is proving to be a very popular chapter, where the draft version was downloaded approximately 8,000 times in 4 months (end Aug 2012 until early Jan 2013).

Bruce Rowse of Carbonetix, Australia for his contribution to review all the chapters in the Passive Design Guideline, providing very useful tips that helped to make this document clearer and easier to understand by building design professionals.

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LEVERAGING LOW EXERGY BUILDING SYSTEMS FOR SYMBIOTIC BUILDING DESIGN IN THE TROPICS

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ABSTRACT

The efficient cooling and dehumidification of building space is one of the key aspects for establishing environmentally sustainable buildings in hot and humid climates. To move beyond incremental improvements using existing systems and technologies, a paradigm shift in building climatization for the tropical climate is necessary. Contrasting widespread, air-based air conditioning systems, hydronic building systems for radiant cooling combined with decentralized ventilation and dehumidification and novel concepts for building operation yield not only to a drastic reduction in energy consumption and CO_2 emissions. As they require much less space for installation they also offer large potentials for the reduction of construction materials and thus for the reduction of grey energy and emissions. Additionally this allows the better utilization of the built volume to achieve a higher ratio of usable space. Parts of this next generation of efficient building systems such as radiant cooling recently have been successfully applied in the tropical context. In this work we outline a complete systems concept that is currently under research and prototypical lab testing as part of Future Cities Lab, LowExergy Module, Singapore. Auspicious results from the lab scale allow extrapolating the concepts to formulate a new approach for symbiotic architectural design that fuse high-performance system characteristics with functional and aesthetic design criteria. This work presents a concept, related building technologies and exemplary synthesis for symbiotic architectural design of office buildings in tropical climates.

INTRODUCTION

The building sector is well known as one of the largest consumers of energy and resources. It accounts for up 32% of global total final energy production (International Energy Agency, 2011) and thus contributes to a significant amount of anthropogenic CO_2 emissions. In hot and humid climates a growing amount of energy is used for building cooling and dehumidification. Additionally, the population in the tropics is expected to rise from 40 to 55% of the global population by 2050 (*Tropical Data Hub - People and Societies in the Tropics*, 2013), further increasing the energy demand.

Building climatization in the tropics is currently main achieved using air-conditioning systems. They often require large amounts of air that needs to be cooled down massively for dehumidification, resulting in large energy consumption and little efficiency. In addition, the necessary ductwork requires large volumes in buildings for horizontal and vertical distribution, which cannot be accounted to the usable space. To build this unusable space and the large ductwork requires large amounts of resources for building materials. In a dense urban context where ground is scarce and inhabitable space has to be created vertically this also has large economical impacts.

To move beyond mere incremental improvements on existing systems for building climatization we propose a conceptual shift. This starts at considering not only the quantities of energy but also their qualities by using exergy as a design criterion. We further promote the decentralization and distribution of harvest, generation and emission of desired effects such as electricity, cold and dehumidified air. Furthermore we advocate the shift from air-based conditioning systems to hydronic, radiant high-temperature cooling systems to drastically reduce the demands of energy, material and space.

This work intends to frame the technical research currently in progress as part of the joint Singapore-Swiss research endeavour Future Cities Lab, Module 1 (*Future Cities Laboratory (FCL)*, 2013). It is based on results of research pursued at the BubbleZERO, a transportable building systems testing facility under real-life conditions, located in Singapore (Bruelisauer et al., 2013). Even though research is still in progress we believe that the results achieved so fare allow extrapolating its potential implications for the design, realization and operation of sustainable buildings with the objective to drastically reduce the required energy in operation, related CO_2 emission and require less resources for their creation.

We further believe that this can only be achieved following a symbiotic approach. The adjective 'symbiotic' denotes our aim for an architecture that does not only integrate technical systems for climatization and energy generation but moves beyond to achieve solutions that are only possible

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due to the interplay of systems and architecture – form, program and structure. Symbiotic solutions intend to leverage the potentials of the participating domains for mutual benefit, to aim for solutions that are of superior performance and architectural quality.

In the following we describe the building systems approach and related technologies. This work however focuses on the potential implications on architectural design and outlines a methodology to facilitate the development of symbiotic design solutions, which will be described afterwards.

A NEW APPROACH

To achieve the aforementioned goals a holistic approach towards the building as a system is necessary. We formulate this approach as an antipode to the existing, indicating a shift in paradigms manifested by the following key concepts.

Low Exergy

The minimization of energy consumption and the increase of energy efficiency are oftentimes postulated as key objectives for building operation. While this is an important goal to achieve the transition towards renewable energy systems, it falls short, however, to describe the efficiency of a thermal system. The concept of exergy allows addressing the notion of 'quality' of a process or a source. This quality is defined by the temperature difference of a heat / cold source relative to its reference environment. To minimize exergy losses, the objective is to achieve the lowest possible difference in temperatures between the inlet and outlet temperatures of a heating / cooling system. The lower the difference, the less high-quality energy (exergy) such as electricity of fossil fuels has to be used. Widely researched, developed and applied in cold and dry climates (Shukuya and Hammache, 2002; Meggers et al., 2012; Schmidt, 2004) the concept of exergy and the 'Low Exergy' approach augment the mere consideration of energy by adding this notion of quality. For the tropical climate research exists related to the concept of cold exergy (Jansen and Woudstra, 2010) but the interpretation and application of the concept and related building systems is novel and present a challenge.

Decentralization and localization

As a second concept, decentralization and localization stresses the aspect of spatial context. Instead of a centralized, hierarchical production and distribution of desired qualities and quantities we aim for the local harvest, production and emission of effects such as energy, fresh air and cold. Localization respects and utilizes the different qualities and quantities available (solar radiation, environmental or process heat sources or sinks) and required (energy, cold, fresh air). This is a constituent part of 'passive' architecture concepts; we however extend this definition to also entail active systems for interior climatization and energy generation. Decentralization potentially facilitates a higher spatial resolution of supply to cater different needs, offers improvements in system efficiency (less temperature and pressure losses) and higher occupant comfort.

Hydronic high-temperature radiant cooling

A key concept towards reduction of energy consumption and exergy efficiency of interior climatization is the separation of sensible and latent cooling. Conventional air-conditioning systems meet occurring thermal loads by using large volumes of cold and dehumidified air. Low supply temperatures of 6°C are necessary to dehumidify the air, which, after that, is even too cold to be supplied to the space. By splitting latent and sensible loads the cooling of the room air can be achieved by a high-temperature hydronic radiant cooling systems using water at 18°C. Studies show a potential of 44% savings or primary energy consumption for example by using a chilled ceiling in combination with desiccant cooling, compared to conventional constant volume air systems (Niu et al., 2001). Whereas hydronic, low-temperature heating has been widely successfully applied in moderate climates (Moe, 2010), its cooling counterpart remains a novelty in the tropical context. Recently, high temperature radiant cooling has been realized for example for the ST Diamond building in Kuala Lumpur, Malaysia (Reimann, 2012).

BUILDING SYSTEM COMPONENTS

These concepts lead to a set of technical system components for the application in buildings. They are outlined in this work only briefly. Every technology for itself is subject to research and application; the reader is therefore kindly referred to the cited publications for more detailed information.

Decentralized ventilation and dehumidification units

Small, integrated ventilation units placed at the façade facilitate decentralized, distributed ventilation (see Fig. 1). Due to the direct supply of exterior air at many locations there is only short ducting of small diameter necessary to transport the air into the space, reducing the pressure losses of the system. Due to the small dimension the ducts furthermore can be integrated into the slab. Whereas the successful and efficient application of the ventilation units has been demonstrated for application in moderate climates (Gaehler and Trochimov, 2013), the additional dehumidification required poses a challenge to its application in the tropics. As part of the research at

the Future Cities Lab, Module 1, prototypical distributed ventilation and dehumidification units have been developed and successfully tested (Saber et al., 2013). Supplying only the amount of air necessary to satisfy indoor air quality leads to a drastic reduction of the ventilation flow thus reducing necessary fan power and dehumidification demand (Bruelisauer et al., 2013).

Multifunctional, radiant cooling panels

Whereas the decentralized ventilation units cover the latent cooling demand in the fresh supply air, the radiant cooling panels cover the sensible cooling demand. In most applications, the panels are mounted directly to the concrete ceiling.

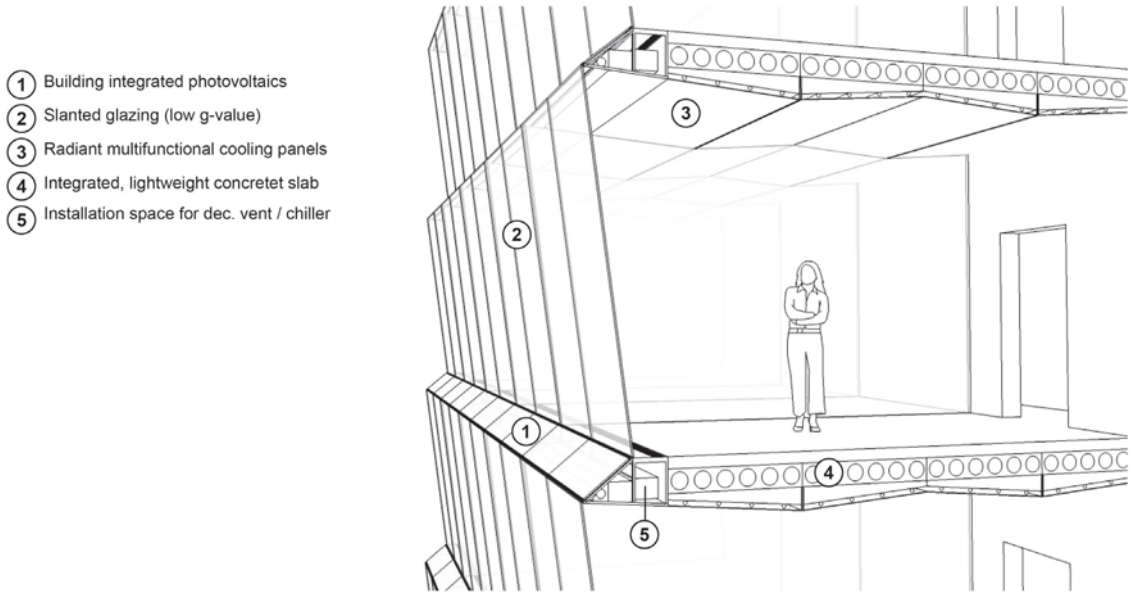


Fig.1: Exemplary building section

Using water as a much more efficient transport medium than air, the necessary amount of space required for installation can be drastically reduced, both vertically (for distribution) as well as horizontally (machines). The piping can be directly integrated into the concrete slabs. Additionally, the slim panels can be equipped with lighting systems, sensors (occupancy, CO_2) and noise dampening features.

Façade integrated photovoltaic cells

In addition to the efficient use of energy, its generation using renewable energy technologies is part of the concept. Due to high solar irradiation close to the equator, solar electricity is considered to be largest renewable contributor to Singapore's energy supply (Luther et al., 2011), even though the fraction of diffuse solar radiation is high. As land resources are small, the largely available surfaces on building envelopes can be employed for solar harvest. The different orientations of building envelope surfaces allow a distribution of the harvest more evenly thus supporting peak of the overall grid ad reducing the need for additional conventional power plants (Luther et al., 2011) to match peak loads.

Distributed Sensing and Control

Distribution and decentralization of system components opens up the possibility for a much more local harvest and supply. This is both a potential and a challenge, as local conditions have to be recognized, communicated and actions initiated.

This requires more information about the local interior and exterior environment, which can be achieved by utilizing wireless sensor and control networks. Local conditions and events such as a rise in humidity lead to a local reaction, addressing the necessary systems at different timescales, for example, utilizing the fast reactivity of the ventilation units versus a slower radiant cooling system. Using the BubbleZERO research lab as a test case, both, a dense wireless sensor network, data acquisition and monitoring as well as distributed control has been successfully developed and applied (Li et al., 2013). To be feasible in a larger scale application, the aim however must be to achieve a reactive system with sufficient performance using the smallest amount of sensors and actuators possible.

SYMBIOTIC LOW EXERGY BUILDING DESIGN

The concepts and the set of technical system components described above open up the possibility to formulate a new approach for sustainable and symbiotic architectural design, in this case focusing on office buildings. It influences crucial and constituting parts of architecture, beginning at the context and the site up to the design of interior spaces. In the following section, these implications are described.

Site and microclimate

In addition to the global climate at a specific location, the individual site context, its local environmental and micro-climatic parameters influence building design. In light of the proposed approach this especially relates to available environmental heat sinks for building cooling. These can found for example in the sea, lakes or green spaces nearby, however of varying degree of temperature difference and thus sometimes of limited usability. Another known factor is the orientation of the building towards and the configuration of building clusters for the harvest of irradiation for electricity production respectively the avoidance of solar gains (Chen et al., 2013). Additionally difference in wind pressures at the façade can be utilized for the support of the decentralized and distributed ventilation (Baldini, 2011). These factors may be considered for the placement and arrangement of buildings as well as to define their orientation up to the placement and sizing of openings.

Spatial program, floor heights and interior surfaces

The distribution of spatial program and its layout can be used to leverage internal cold sources from spaces that require lower interior temperatures to spaces that are comfortable at higher temperatures temperature. Establishing a cold cascade, air once cooled down and used in the space can be used to support the cooling of adjacent spaces for example after occupancy in the initial space ends. Low temperatures can be exchanged dynamically, for example cooling down occupied spaces in the morning and recapturing / re-using the cold air for other spaces that are occupied in the evening. Local differences in temperature requirements can be leveraged for energy savings using the proposed decentralized systems and water as an effective distribution medium. Separating sensible and latent cooling, using hydronic high-temperature cooling and distributed ventilation systems directly influences the design of interior spaces. As there is no need for a primary distribution with related large size ducting to distribute the air within the building large volumes that are normally occupied by ductwork can now be used for the actual room height, reducing the total required floor height. The use of high-temperature radiant cooling requires interior surfaces as large as possible in order to keep the supply temperatures high. The placement, sizing and accessibility of radiating surfaces influence the interior design of a space and can be leveraged for design purposes (see Fig.1).

Multifunctional Envelope

For the proposed approach the envelope is used not only as an airtight boundary between interior and exterior climate but also hosts a range of functions and technologies. This includes systems for solar electricity generation, air supply / dehumidification and eventually small size, distributed chillers (see Fig.1). Through the envelope the space behind is served with necessary daylight, fresh air and electricity at a high spatial resolution, catering to its specific and dynamic demands. This additionally frees the interior space from large amounts of distribution infrastructure, providing more flexibility in spatial partitioning and more design options concerning surfaces, for example for radiant cooling. To limit internal solar gains the panels of the glazed façade are slanted inwards, resulting in a shading

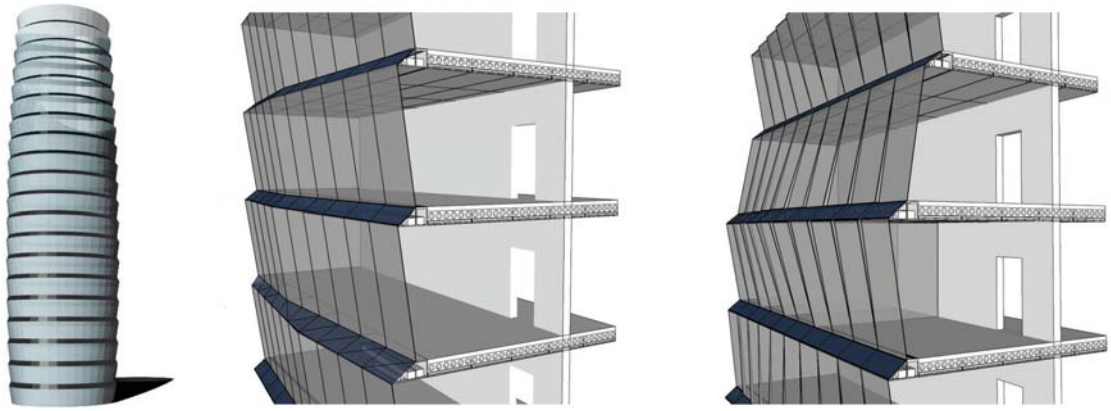


Fig 2: Exemplary building / façade morphologies

effect similar to horizontal shelves. In a slightly different application, this principle has proven successful in recent high-performance buildings such as the ST Diamond building in Kula Lumpur, Malaysia. Additionally, glazing with a low solar energy transmittance and high selectivity (Oelhafen, 2007) is chosen to provide excellent daylight quality and perception of the exterior combined with low solar gains. The 'short leg', the horizontal extension of the tilted glazed façade can be used for solar electricity harvest using photovoltaic cells, providing optimal orientation as well as shading. Potential build-up of heat due to insolation can be removed by shaping the fixture in a way air can freely move around the panel. As the panel heats up, the air behind is heated and escapes through openings at the top, drawing cooler air from below the panel, potentially cooling down the cell. Dependent on the orientation of the façade, the size and shape of the slanted surfaces can be adapted (see Fig.2).

Integrated floor slabs

As the approach advocates not only the reduction of emissions in operation but also material efficiency, the materialization of the building structure is of eminent importance. As the components and their means of distribution are small they can be integrated into the load-beating slabs in between the structural reinforcement. This reduces the necessary amount of floor height as well as the amount of concrete necessary. The embedding of media distribution such as air or water has been extensively and successfully applied in buildings in Europe (Moe, 2010). To achieve even lighter structures, the dead space between the structural reinforcements can be filled with cavities to reduce the amount of concrete necessary. As a side effect, the reduction of thermal mass enhances the quickness of the radiant cooling system to react to load changes in the interior.

Building Morphology

As a result of this bottom-up methodology, the assemblage of constituting elements can lead to new building morphologies. Acting not only as technical but also formal design parameters, the surface dimensions and angles applied on the envelope define the overall building shape. Combined with site-specific parameters such as orientation or consideration of neighbouring buildings the global building form reflects the Low Exergy design parameters on different scales (see Fig.2).

PERFORMANCE-BASED DESIGN PROCESS

The proposed approach also advocates a different design process as an increased amount of design parameters also increases design complexity. As can be stated for performance-based design in general, the shift towards a holistic design approach means needing to know more at an earlier stage in the design process. The Low Exergy approach additionally requires the architect to consider the relationship and dependencies between implementing the various passive and active systems, resulting in a significant number of design parameters. For the implementation of radiant cooling panels, as an example, the amount of surface area and temperature required is highly dependent on the quality of the building envelope, orientation and occupation. It is therefore important to factor in these constraints and limitations in the early design stage where alteration can be easily made. This posts the challenging task of obtaining data related to thermal properties of materials and space already during conceptual building design.

The use of environmental simulations programs facilitates the design process by providing information on thermal performance without the need to manually perform complex thermal equations. The architect can weigh his design actions on the building as a system by examining the thermal data and using it as a feedback. The Design Performance Viewer (DPV) (Schlueter and Thesseling, 2008) represents an approach of fusing Building information Modelling (BIM) and environmental simulation. In DPV feedback on design action are reflected directly on the digital model. However, the task of manually constructing the model limits the number of design options that can be explored.

The introduction of parametric modelling and optimization enables the architect to explore more design options by automating the design generation and feedback process (Chen et al., 2013). In such a digital design environment, different modelling and simulation programs are set up to generate necessary data for the design of Low Exergy architecture (Fig. 3). The large amount of data generated can be analysed and gives a better understanding of the design issue at hand. As a result, the architect can grasp the relationship between the various design parameters ranging from envelope, structure to building systems. Utilizing a scientific workflow system (Thomas and Schlueter, 2012; Chen et al., 2012) allows to customize the flow of data from modelling and simulation to optimization steps specific to the design question and building characteristics.

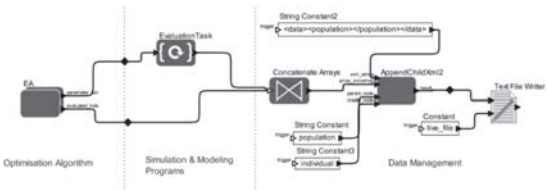


Fig 3: Diagram describing the ecology of digital programs using scientific workflows

RESULTS AND DISCUSSION

We presented a conceptual approach based on a new set of guiding principles and related technologies targeting a drastic reduction of energy consumption and related carbon emissions for building in the tropics. The aim of this work is to frame a holistic approach and explore symbiotic architectural design necessary for its realization.

As there has is no physical implementation of the entire concept yet, results can only be presented and validated for the individual aspects and components. The BubbleZERO laboratory acts as the main enabler for research, testing and validation of partial concepts, systems and components. First results indicate the general feasibility (Bruelisauer et al., 2013), for example related to successful ventilation and humidity control without condensation. Further research at the laboratory targets the proof of concept for up scaling to a larger testing environment.

Using standard high-rise office buildings as a reference, the application of the concept in Singapore also promises a large economic impact. The volume used for installation in office buildings often accounts for up to 1/3rd of the floor height. The approach presented allows freeing this volume and thus bears the potential of up to 1/3rd more usable space at the same building height.

Concerning user comfort, the approach bears the potential for improvement due to localized and individualized comfort settings made possible trough the degree of decentralization and distribution. The proposed systems additionally causes less noise pollution as the hydronic cooling is not audible and the fans of the decentralized units are small and move much smaller amounts of air. This also contributes to much less uncomfortable states due to cold air sensation. This is undermined by research where it is stated “chilled ceilings improve thermal comfort because cooling is provided directly and more evenly to the occupants without causing drafts” (Chowdhury et al., 2008, p.451).

The main technical challenge for realization is the prevention of condensation in the interior space. This means designing the systems described above to be capable of effectively removing humidity from the outside air as well as maintaining an interior temperature below dew point. To prevent infiltration the façade has to be sufficiently airtight. Utilizing the distributed components, sensing and control, changes in occupancy can furthermore be anticipated and prepared accordingly, for example by increasing the local ventilation rate.

From an economic viewpoint the proposed approach leads to higher investment costs due to the more advanced materials and system components. This however pays off by drastically reduced energy costs, higher user comfort and satisfaction and the freeing of usable floor space, as mentioned above.

CONCLUSION

The approach presented offers manifold potentials if the building is conceptualized and designed as a system, stressing the symbiotic relationship between the different elements that constitute architecture.

At the time of writing, preparations for a large-scale case study are underway that will open up the opportunity to further develop, realize and validate the concept. If successful, the approach bears the potential of achieving a quantum leap in terms of ecological efficiency for office buildings in a tropical context, combined with better allocation of usable space and thus economic benefits. As we show in this work, this additionally opens up possibilities for architectural and urban design that utilizes local potentials and better adapts to user needs.

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INDOOR CLIMATE SOLUTION
PUTTING TOGETHER SUSTAINABLE CONSTRUCTION AND ECONOMY

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ABSTRACT

This document introduces Indoor Climate Solutions (ICS). ICS is a building cooling system, which takes advantage of the thermal mass of construction elements, such as slabs, walls or screeds.

Compared to air operated A/C cooling systems the water operated ICS cooling systems provides

- energy savings
- better thermal comfort
- higher design flexibility
- increased spatial efficiency
- ease of maintenance
- lower total cost of ownership

The principle of thermal activation is well-engineered in Europe and parts of North America. As Asia becomes more urbanized, construction sector is challenged to look for alternative solution that can help building to be more environmentally friendly and economically sound. The next step for a broader success in Asia is to make developers, architects and specifiers more familiar with the system and its characteristics.

INTRODUCTION

The reduction – if not elimination – of our building stock's energy consumption is the real estate industry's top priority. This is all the more important as most modern buildings abandon traditional cooling techniques – such as shading and natural ventilation – and rely on mechanical cooling and ventilation by default.

Traditional HVAC systems are air operated. The advantage of theoretically unlimited cooling capacity comes along with the handicap of an inefficient system: Air's thermal storage capacity is poor; the electricity required for moving air through fans and ducts is tremendous.

Indoor Climate Solution (ICS) is an under floor cooling system for high performance buildings. The under floor cooling system uses the concrete floor's thermal mass storage and discharge of thermal load. This allows conserving energy by reducing the load on traditional HVAC system during operational hours.

PRINCIPLES OF THERMAL COMFORT

Behind the idea of ICS stands the principle, that thermal comfort of people in a room is a function of air temperature and radiant temperature from surrounding surfaces: Warm surrounding surfaces require relatively low air temperatures, to compensate the radiant heat and make us feel comfortable.

The same principle work also the other way around: If the surrounding surface is relatively cool, the indoor air can be warmer without people feeling too warm.

This leads to the simplified corralation for thermal comfort:

$$cool\ air\ +\ warm\ surfaces = warm\ air\ +\ cool\ surfaces$$

Subsequently by providing a radiant cooling through the indoor surfaces the room temperature can be increased with the same thermal comfort (figure 1).

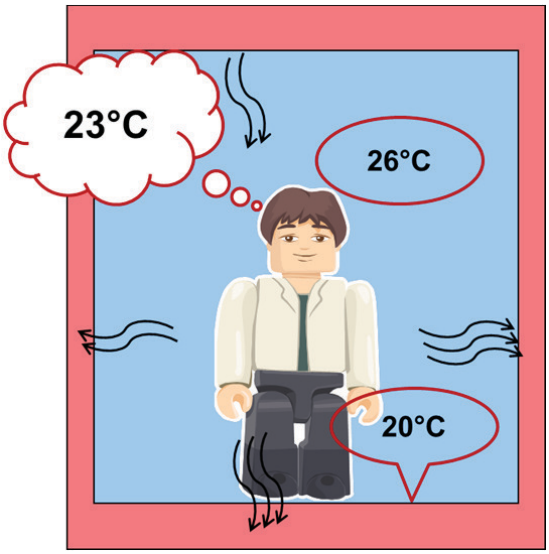


Figure 1
Operative temperature we feel

TECHNICAL APPLICATION

The starting point for ICS is the design of the slabs, in some cases also the surrounding massive walls.

Prerequisite for ICS are massive construction elements with extensive direct contact to the indoor

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ambient air. The construction elements can be cooled in two different ways:

Thermally Activated Building Structure (TABS)
TABS is a massive construction element which gets thermally activated by water filled tubes implemented into the element. Typically, a tube mesh gets installed into a concrete formwork before pouring the concrete.

Cooling with TABS operates into all directions of a construction element, in case of a slab to the rooms above and underneath. This makes the system most efficient, given that no suspended ceiling or thick carpet is reducing the thermal transfer.



Figure 2
TABS section of a slab

Under floor Cooling (UFC)
UFC is a thermally activated screed on a slab. As for TABS, water filled tubes are installed into the screed. The difference is that the screed is insulated towards the slab underneath, so the coolness is only provided to the room above.

Though not as capable as TABS, UFC is applied where a flexible design for the ceiling is required.

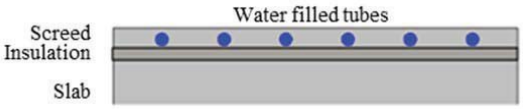


Figure 3
Under floor cooling section of a slab

No matter which of the above cooling techniques comes into place: The entire system has to be embedded into a holistic building concept to unearth the full potential. Main aspects of the building design must consider:

- Building orientation
- Floor layout
- Solar protection / shading
- Thermal insulation of façade and roofs
- Indoor air flow
- Building Environmental Management System

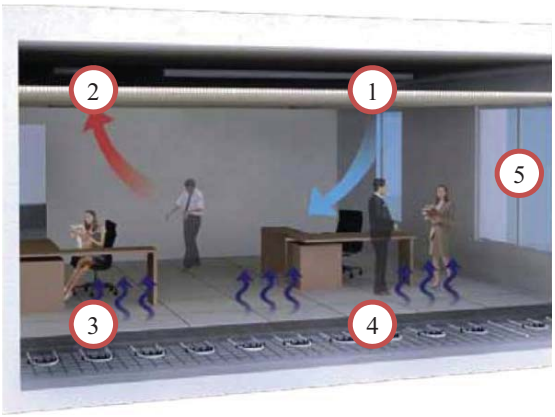


Figure 4
Integrated room layout with ICS

Figure 4 shows the ideal design elements for a typical office space with ICS (here with UFC):

1 Dry and cooled air array integrated into suspended ceiling with less volume
2 Used air outflow
3 Radiation cooling effect
4 Water cooled concrete slab (19-20 degrees)
5 Insulated façade and high performance windows with sun shading

OPERATIONAL BENEFIT OF INDOOR CLIMATE SOLUTION

Reduced cooling demand
A rooms cooling load is mainly defined by three paramenters:

Q_{int} Internal loads (electrical appliances, IT, people)
Q_{sun} Load from sun radiation (through glass façade)
Q_{cond} Conductive load from external heat intruding through the façade or roof

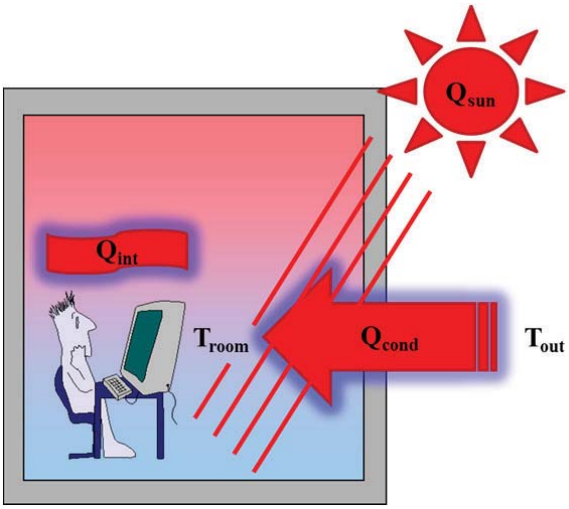


Figure 5
Cooling loads in an office room

The conductive load Q_{cond} is proportional to the difference between the outside temperature T_{out} and the indoor room temperature T_{room}:

$$Q_{cond} = A * \frac{k}{x} * T_{out} - T_{room}$$

A = surface area
k = thermal conductivity
x =surface thickness

With radiant cooling the room temperature T_{room} can be increased maintaining the same thermal comfort. This reduces the conductivity load Q_{cond} and therefore the overall cooling load.

Higher efficiency with water as cooling medium

The heat storage capacity of water is more than four times higher than that of air (4'200 to 1'000 Wh/kgK). This makes water operated cooling systems more efficient than air operated systems:

- Subsequently the temperature of the cooling medium can be raised closer to the aimed indoor air temperature, which reduces the overall required cooling power.
- Moving small quantities of water by pumps requires less electrical energy than moving large volumes of air by fans. To remove 1 kW heat from a room an A/C ducting system needs ~ 140 W for the ventilator, whereas a radiant cooling system needs ~ 3 W to run the circulation pump.

Reduced air conditioning size

ICS operates in a combined system of radiant cooling and air conditioning (A/C).

Whereas in conventional systems the A/C-system layout is determined by the total cooling load, in ICS the A/C-system is dimensioned to match just the (far lower) hygienic fresh air demand.

With radiant cooling the cooling power load for the A/C system can be reduced.

The reduced air change volume together with the higher room temperature is also reducing the required energy for dehumidification.

Thermal comfort

Conventional A/C-systems have an asymmetric temperature profile. Close to the air outlets the temperature is very cool and raises to very warm with increasing distance to the air outlets.

The imbalanced temperature distribution leads to draught and zones of limited thermal comfort.

Radiant cooling has an equal temperature profile all over the room surface area without draught.

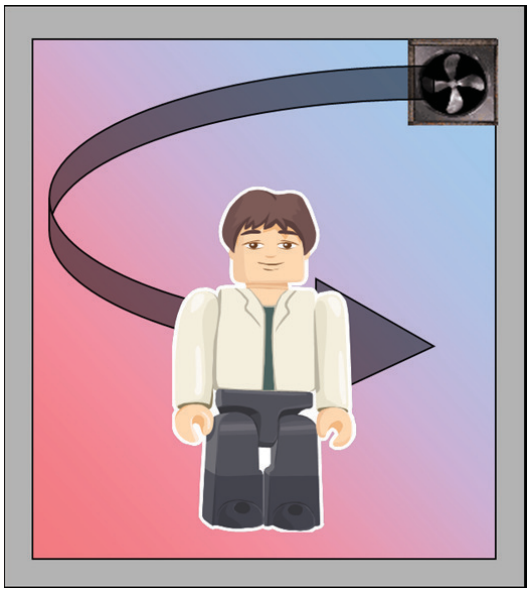


Figure 6
Asymmetric temperature profile in an A/C layout

Hygienic aspect condensation

The low outlet air temperature of A/C-system bears the risk of humidity condensation around the air outlets: for a room temperature T_{room} = 23 °C and a humidity of 55% the dew point temperature is ~ 14 °C, not an uncommon air temperature for A/C-systems. The condensation leads to discomfort, impairment health and building damages.

With radiant cooling, operated at temperatures of 18-20 °C, the surface temperature is kept above the critical condensation temperature.

Thermal comfort zone (in high ceilings)

In high rooms A/C systems have to change the room's entire air volume, although the comfort zone is only required in the bottom part of the room.

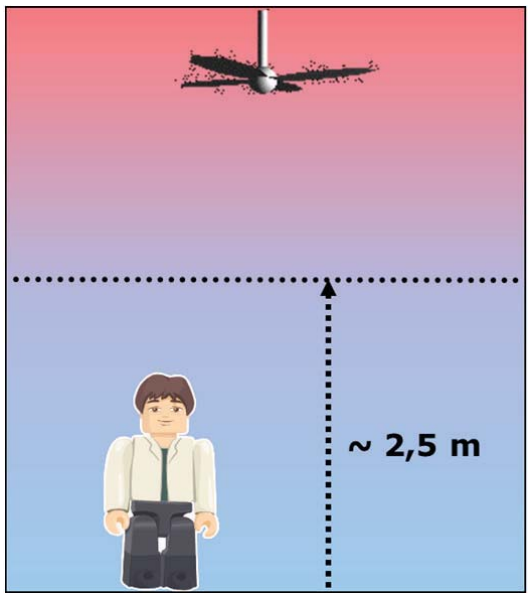


Figure 7
Ideal temperature distribution in a high ceiling room

For the thermal comfort of people it is sufficient to create a comfort temperature in a zone up to ~ 2.5 m above the floor. Conditioning the air above means cooling down unnecessary air volume and wasting cooling energy.

With a radiant floor cooling system this can be realized without compromising the thermal comfort of the use space.

Sun radiation on floor

A special benefit of radiant floor cooling is to remove heat from sun radiation onto the floor of large halls like atriums or lobbies with glass façades. Extinguishing the thermal load at its very origin is the most efficient way of cooling.

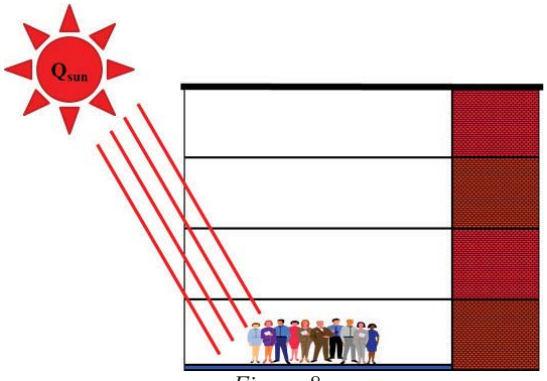


Figure 8
Heat load by solar radiation in large atriums

With radiant floor cooling the floor temperature is kept low and the heat transfer to the room is decreased.

Saving maintenance costs

An A/C-system operates ventilators, ducts, outlets, air filters and fire dampers, which all have to be inspected and maintained regularly. Ducts and fire dampers are usually hidden behind suspended ceilings and in duct ways, which makes them hard to access.

A radiant cooling system works practically maintenance free as the tubes are embedded in concrete and the water runs in a closed system.

IMPACT TO BUILDING DESIGN

The large size of air ducts in a convectional cooling system makes them a critical design issue. Not only they consume considerable building space and volume, due to technical constraints later changes in the building layout are under the reserve of the adaption to the ducts. This makes the building less flexible for future changes.

Reduced floor height

The overall smaller ducting dimensions of an ICS cooling system allow either more flexibility or less technical height for suspended ceilings. The potential of reducing the storey height varies from 40-60%.

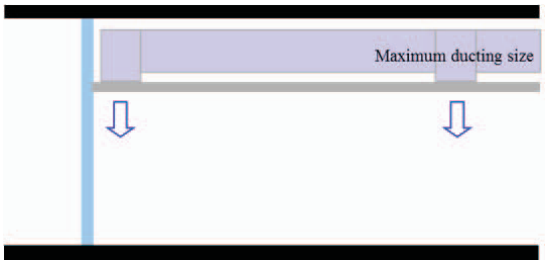


Figure 9
Baseline: Full air convection cooling with maximum ducting size

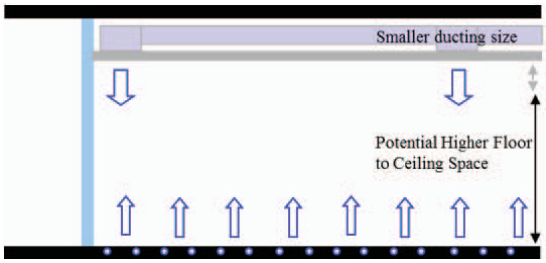


Figure 10
Integrated UFC: Potential to reduce ducting by 40-60%

The saved height can be used either for higher interior space (=higher comfort and flexibility) or more storeys.

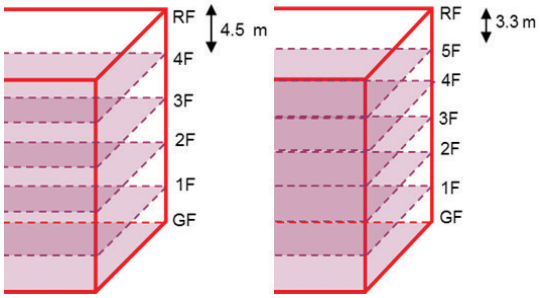


Figure 11
Comparison of storey height between A/C-systemand ICS

Higher spatial-economy and flexibility

The reduction of air ducts benefits the built area at least to the same extent as it helps the floor height. The improved spatial-economy leads to reduced construction costs.

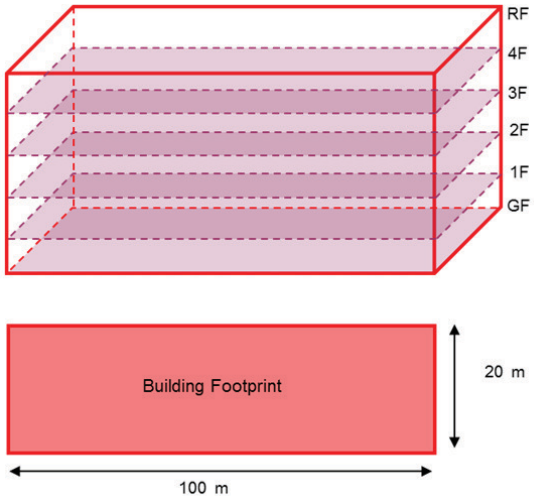


Figure 12
Baseline: Full air convection cooling with maximum ducting size

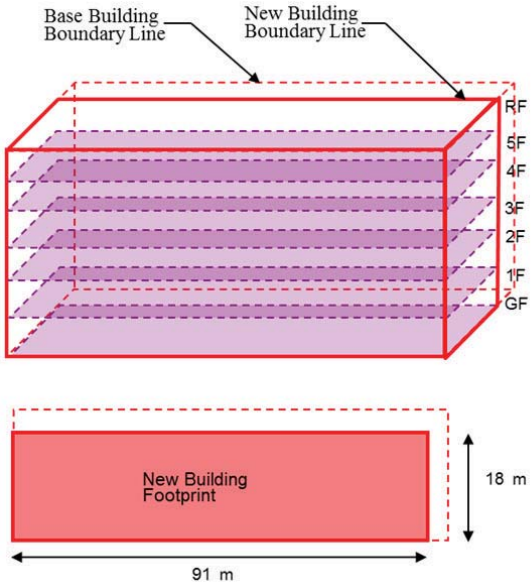


Figure 13
Integrated UFC: better spatial-economy by 10-20%

More important than construction cost is the improved flexibility. For layout changes in office buildings the large vertical ducts are the main obstacle, since their position and dimension hardly can get changed.

Both improved efficiencies, in height and in space, lead to reduced construction cost or more usable space built at the same expenses.

TOTAL COST OF OWNERSHIP

To better understand the life cycle performance of ICS a comparison of an ICS building with an building operated with conventional A/C system has been conducted.

The comparison includes the construction costs as well as operation energy costs. The energy consumption has been simulated based on a dynamic thermal simulation software.

The general assumption for both buildings are:

- Office use
- 2'000 m^2 floor plate area
- 15 storeys
- 30'000 total office floor area

The ICS building is equipped with TABS (thermal activated building system) and an improved thermal insulation of façade and roof)

Construction cost comparison

Description	Cost [IDR/m2]		Deviation
	Conventional	ICS Building	
Sub structure	400'000	400'000	0.00%
Upper structure	1'200'000	1'150'000	-4.17%
M & E	2'400'000	2'600'000	8.33%
Architectural	2'050'000	2'224'250	8.50%
External	412'500	412'500	0.00%
Total	6'462'500	6'786'750	5.02%

Description	Total cost		Deviation
	Conventional	ICS Building	
Sub structure	12'000'000'000	12'000'000'000	0.00%
Upper structure	36'000'000'000	34'500'000'000	-4.17%
M & E	72'000'000'000	78'000'000'000	8.33%
Architectural	61'500'000'000	66'727'500'000	8.50%
External	12'375'000'000	12'375'000'000	0.00%
Total	193'875'000'000	203'602'500'000	5.02%

Table 1
Construction cost comparison

Due to the higher investments for technical equipment and better insulation, the ICS building requires approx. 5% more capital than the conventional building.

Operational cost comparison

For the comparison of operational costs, only the electricity costs has been taken into account. Addressing the insulated façade, integration of ICS system, control mechanism, the ICS building potentially results higher efficiency of up to 50% compared to the conventional A/C system.

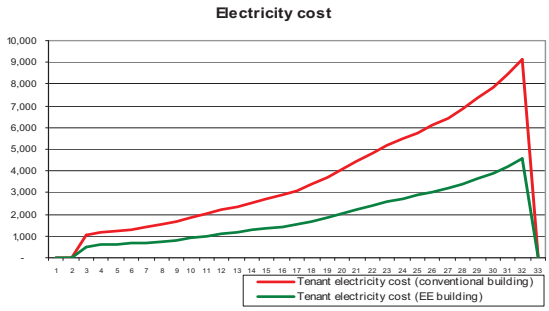


Figure 14
Electricity cost comparison ICS vs. conventional A/C

Total cost of ownership

Over its lifetime, the building would require less energy to provide a comfortable and healthy indoor environment for its occupants. This translates to lower operational cost for the building owner, and bigger cash-flow which can be utilized for the marketing activities, maintenance program or other investments. While leveraging on the superior comfort of radiant cooled building, and the rating points for green building certification, building owners can start to differentiate their portfolio through the integration of ICS system and achieve higher revenue from leasing a healthier and greener building.

	RESULT *(in IDR Mio)*			
Figure	Conventional building	EE Building	Reduction / Comparison	%
Acquisition cost	(193,875)	(203,063)	(9,188)	5%
Operational revenue	3,603,404	3,820,347	216,944	6%
Operational cost	1,781,649	980,216	(801,432)	-45%
Operational profit	1,821,755	2,470,657	648,902	36%
Net profit	1,465,092	2,040,835	575,743	39%
Cash Flow	1,465,092	2,040,835	575,743	39%
NPV	106,704	189,060	82,356	77.18%
IRR	16.31%	19.05%	2.74%	17%
Pay back (yrs)	9	8	(1)	-11%
Electricity consume (MWH)	145,152	72,576	(72,576)	-50%
Total electricity cost	982,710	491,355	(491,355)	-50%
Electricity cost by tenant	117,925	58,963	(58,963)	-50%
electricity cost by Developer	864,785	432,392	(432,392)	-50%
CO2 Emision (ton)	129,476	64,738	(64,738)	-50%

CONCLUSION

This paper describes the technical and financial properties of ICS, a radiant cooling system relying on thermal activation of the building structure.

Especially in Europe, also in parts of North America, radiant cooling (and heating) is widespread and common technology for commercial and residential buildings. Experiences establish the improved thermal comfort and the significantly lower energy consumption of the system. This all adds up to far lower total cost of ownership and lower carbon footprint over a building's life cycle.

In this, ICS and similar radiant cooling systems are an important step towards the low carbon society.

ACKNOWLEDGMENT

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AIR FILTRATION FOR ENERGY SAVINGS, BETTER IAQ AND WORK PERFORMANCE

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[1]Innovative Plant Technology, Australia

ABSTRACT

Building rating schemes deliver code compliant "acceptable" quality indoor air to building occupants. Less than optimum air has a significant effect on decision-making performance. Clean, pollutant free "rainforest" quality indoor air through active botanical air filtration, a natural process, directly in the workplace, complements the HVAC filter system, removing volatile organic compounds (VOC's), air-borne bacteria, dust, and mould, and reduces the need for high ventilation rates. Case studies show up to 20% energy savings in HVAC operations can be achieved from lower ventilation rates in existing buildings, and less need to over-size HVAC systems in newly designed buildings, with lower ventilation costs of 3 - 5%, improved work performance of 6 – 26% increase, and a payback period of less than two years.

INTRODUCTION

Good indoor air quality safeguards the health of building occupants and contributes to their comfort, wellbeing and work performance. Poor indoor air quality in the workplace leads to discomfort, ill health, absenteeism and lower productivity. Green air is not necessarily clean air and the drive for energy efficiency without sufficient regard for building occupants can have significant adverse economic consequences

Perceived air quality is the basis for current ASHRAE guidelines and stanadards for ventilation (ASHRAE Guidelines 10, 2011), applied universally. Occupant evaluation is subjective and not indicative of health risks associated with breathing polluted air, confusing air movement with air freshness (ie. free of pollutants) (Melikov and Kaczmarczyk, 2012) The conventional approach to improve indoor air quality is to increase the ventilation rate to dilute pollutants in the workspace, however the additional airflow from the various ventilation modes substantially increases building operating costs, consuming as much as 30% of the total energy use (US EPA, 2000), with little appreciable improvement in "breathable" air quality.

Some green buildings claim a designed 50% increase in ventilation rates above code requirements gives better air quality. "From an energy and climate change perspective, we want to reduce ventilation rates." (Fisk et al. 2012). There is considerable mechanical system that is over design with the gap between operational loads and design loads leading to a 20% increase in air conditioning system in energy use (Younes and Carter 2006).

Economics of high quality indoor air

Local filtration in the workplace reduces unwanted gaseous pollutant and particle re-circulation, with potential improvement in productivity from breathing cleaner air, while providing protection for the HVAC components.

Active living wall air filtration has the capacity to supply clean, filtered air equivalent to 80% of the required outdoor air supply for an office space, resulting in reduced energy costs from lower ventilation rates, reduced maintenance/replacement of fans and filters (Zhang 2010).

Cost perspective

As salaries (plus on-costs) are the major office building expense, even small improvements in indoor air quality can have a major effect on operating costs and efficiencies. Productive employees accomplish more output, and more output means better value and lower costs. Increased worker performance brings a distinct economic advantage. For example, the savings from a modest 1% increase in performance could be sufficient to offset a 50% increase in energy costs in many buildings (Lawrence Berkeley National Laboratory, 2012). However, with active living wall air filtration, a decrease in energy costs of 3 – 5% can be achieved as well as improved worker performance.

What are we actually breathing?

Ventilation "fresh air" is generally contaminated, mostly with motor vehicle emissions that combine with a multitude of contaminants generated indoors from building materials, various operational activities, and building occupants, to form a highly interactive toxic mix of air pollutants.

Building codes mandate that new (and green retrofit) buildings be designed for ventilation rates appropriate for maximum occupancy, a condition that almost never exists. A building whose ventilation rate is code compliant is already over-ventilated the vast majority of the time, (Younes and Carter 2006), so providing ventilation over and above code requirements may provide little or no health benefit while substantially increasing energy consumption.

There are no regulations on chemical emissions from commonly used building materials. De facto environmental certification schemes have been developed by industry associations that include material

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emission limits, but the legal standing of these certifications raise considerable doubts.

Example No-VOC paints

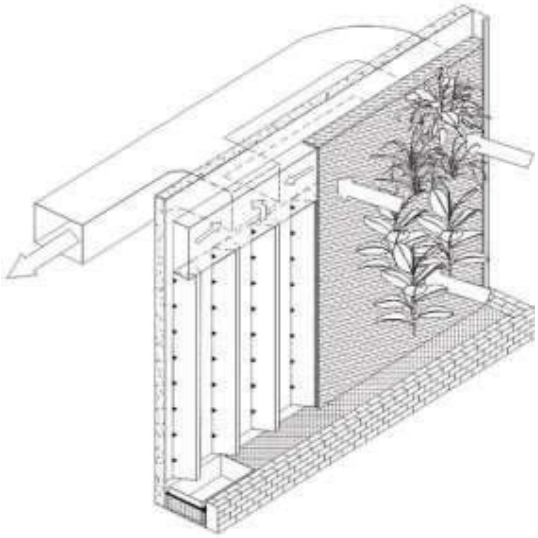
According to the U.S EPA "no-VOC" latex paint does not necessarily mean no emissions. Colouring tints contain high VOC levels, and linseed oil used as a drying agent in "low VOC paints" reacts with ozone, nitrogen oxides or hydroxides (usually from outside supply air) to form oxidation products that are potentially irritating or harmful to health.

Many studies are now demonstrating adverse health effects at levels of air pollutants well below published air quality guidelines. Neither indoor nor outdoor environmental sampling is a good predictor of personal exposure, nor energy rating systems an indicator of clean, uncontaminated indoor air.

Code compliant carbon dioxide levels

Carbon dioxide levels are often used as a surrogate for occupancy levels and for determining ventilation rates. Recent findings from the U S Department of Energy's Lawrence Berkeley National Laboratory (2012) show that even code compliant carbon dioxide levels (700 – 1000 parts per million (ppm), typical of the lower levels

Figure 1 – Schematic make up of an active indoor air biofilter
(Image courtesy of Nedlaw Living Walls Inc)



in many offices, have significant adverse effects on decision–making performance. Carbon dioxide levels up to 5000 parts per million have been measured in some offices, particularly in the afternoon and with high occupancy rates. The most dramatic declines in performance were for "taking initiative and thinking strategically." (Lawrence Berkeley National Laboratory, 2012). An active living wall biofilter has excess capacity for absorbing carbon dioxide (Wood 2006).

Air filtration

Air filtration is a critical component of a building's energy performance, so HVAC filters should be considered as energy using products. The key issue in filter energy efficiency is the filter's pressure drop. Increasing outdoor air quantities in mechanical ventilation systems will usually lead to increased coil sizes, and possibly increased chilling and heating plant capacity. New filters can be a source of pollutants after three months of operation, yet the average filter lifetime can be 6 months to 12 months and are generally not changed until the pressure drop reaches the recommended replacement value. Consequently increasing the outdoor airflow rate reduces the benefits of cleaner air that should result.

Engineering solutions - Existing buildings

Existing buildings that have the greatest difficulty in raising outdoor airflow rates to meet current standards were built with energy efficiency in mind and may have the least excess capacity.

As an example, The Building Code of Australia (BCA 2012) has mandated ventilation rates appropriate for maximum occupancy. Occupancy rates can vary depending on workspace design and use. Conventional Variable Air Volume (VAV), Constant Air Volume (CAV) and Fan Coil Units (FCU) systems all employ the 'perfect mixing' principle. This will unavoidably mix all the pollutants in the indoor space before they are re-circulated for exhaustion or re-conditioning. The displacement system (DS) has the advantage of limiting the diffusion of the pollutants.

One major problem of conventional design is the lack of a method to control the path of the contaminant air. For general ventilation, it consists of dilution and removal of contaminants; airflow patterns within rooms; airflow direction within the space and negative pressure in rooms. Direct source control with air cleansing is the only method to capture contaminants at or near the source.

Various engineering solutions are employed to control and reduce operating costs. Managing the hours of operation of the ventilation system, e g, switched off overnight, airflow reduced to 10% overnight or continuous 100% operation.

Turning off the ventilation system or reducing the airflow outside working hours significantly increases the pollutants emitted by the filter immediately the system is turned on, and has been shown to persist for up to two hours.

High quality filtration – health effects

Providing high quality filtration in the workspace, not only delivers substantial energy and cost savings, but also has a measurable effect on building occupant health and wellbeing and performance improvement. Although HEPA filters provide high filtration efficiency, they remove only particulates and require activated carbon

filters to remove gaseous pollutants (VOCs). They are generally not recyclable and become a source of toxic waste. Existing HVAC systems cannot usually be upgraded to HEPA filters without a complete retrofit of the air handling system, due to the high pressure drop and potential leakage associated with them.

Pressure drop

The pressure drop across the mechanical filters in a typical HVAC system in a standard office building increases fan energy use with the build-up of "filter cake", adversely affecting air-conditioning system performance and efficiency (Nassif 2012). It is generally designed to be less than or equal to 124Pa. but the pressure drop across a HEPA filter can range from 250 – 500Pa. Local filtration reduces unwanted gaseous pollutant and particle re-circulation, with typical system pressure drops of less than 75Pa, mainly from the diffusers There is a clear need for a low-pressure drop filter that removes hazardous or harmful contaminants, effectively.

Active living wall air filtration

To provide clean, pollutant free air to building occupants, direct source control with air filtering is the only method to capture contaminants at or near the source. Australian Standard AS 1668- 1.2, 2012, The use of ventilation and air conditioning in buildings Part 2 Appendix D allows, "cleaning recirculated air to provide an equivalent dilution effect (i.e.) equivalent outdoor air.

The active living wall air filter (Figure 1) is a dynamic system, improving indoor air quality directly in the workspace. A vertical hydroponic green wall (soilless) is designed as an active living, self regenerating air filter, removing indoor contaminants such as particulate matter, volatile organic compounds (VOCs), bacteria and viruses, allowing clean fresh air to be distributed throughout the space by the mechanical ventilation system.

Operating 24/7 and strategically located, active living wall air filters can present an environmentally positive corporate image, while making a real difference in "breathable" air quality (Figure 3). Biofiltration of the air circulating within the building envelope enables clean, cool air to be delivered, reducing the need for 20-30% outside air to be conditioned, saving commensurate energy costs, and contributing to thermal comfort by on average, a 0.5^{o}C temperature decrease and 15.0% RH increase.

Figure 2 An example of a typical payback period

Example

Two Living Wall filters each 2.4m wide x 1.7m high totalling ~ 8 m^2 are installed to filter the air in an open plan workspace of NLA 450 m^2 at a cost of $24,000 ($3000 per m^2)

(At a workplace density of 10m^2/person (AS 1668.2) this provides clean filtered air for up to 45 occupants).

Simple Payback Period

Payback Period (years) = $ Capital investment / $ Annual Savings

Assuming an occupancy rate of only 20 persons, and a 1% improvement in performance, as a straight-line approximation, at an average salary cost of $72,000 (Australian Bureau of Statistics, May 2012), this becomes $720 per person, a total of $14,400

Payback Period (1.7 years) = $ 24,000 / $14,400

Similarly at a full occupancy rate payback time would be considerably shorter

There are additional energy savings from reduced ventilation rates, lower filter pressure drop, and less maintenance and replacement costs of HVAC fans, filters and pumps, and by avoiding design over-sizing.

Biofilter maintenance costs equate to less than $10/$m^2$floor space/p.a.

Clearly minimal costs compared to potential savings.

Active living wall energy requirements

Minimal power consumption is required for a small water recirculation pump of 2 kWh/m^2 floor area and a plenum extraction fan of 0.2 kWh/m^2 floor area The power consumption for the water pump for a total 2.2 kWh/m^2

Additional energy reduction is achieved through automated controls set for the fan to operate only during occupied hours, however the water recirculation pump needs to operate continuously.

For comparison, the Property Council's best-practice existing office building tenant light and power consumption is 62.5kWh/m^2 for a building in operation 10 hours a day, 250 days a year. NABERS (ABGR) 5 Star benchmark for office tenants is equivalent to 52kWh/m^2. Clearly, the energy consumption associated with an active living wall air filter is relatively minor, and represents minimal ongoing energy costs.

CONCLUSION

Active living wall air filtration, a self-regenerating air filter solution, gives the option of minimum code-compliant fresh air rates while delivering high quality clean, fresh air to building occupants at low cost, with a less than 2 year payback, either incorporated into the building's air handling system or as a free standing unit, ranging from room size to multi-storey.

Good indoor air quality safeguards the health of building occupants and contributes to their comfort, wellbeing and work performance

The technology can have a substantial impact on the energy balance and air quality of the space, as well as reducing ventilation costs, and "lower capital costs due to smaller mechanical and electrical infrastructure" (Younes and Carter 2006), while requiring a very small footprint.

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Figure 3 – Active Living Wall installation in a commercial office reception area. (photo courtesy of Umow Lai)



THE USE OF GREEN BONDS IN SUSTAINABLE DEVELOPMENT

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ABSTRACT

Green bonds are fixed-income financial instruments, with which the issuers raise debt capital to fund projects with environmental benefits. Most green bonds issued to date have been used in climate change mitigation projects, including use of renewable energy, improvement of energy efficiency, transport-related projects (such as mass transit) and water technology. To-date, approximately USD7.2 billion of green bonds have been issued. Issuers include multi-lateral agencies (e.g., World Bank), private, public and state-owned organisations. Most green bonds issued are plain vanilla treasury-style retail bonds, or asset-backed securities tailor-made for specific green infra-structure. For the green bond market to grow, the scale of issue, liquidity and monitoring would be important. Necessary conditions for a green bond issue include an investement grade rating and above, whilst the size also matters. Hence, there is a need to study the factors leading to the success of a green bond issue. As investors have picked up confidence in bonds after the sub-prime crisis, and taking advantage of the prevailing low interest rate environment, bonds have a niche compared to bank loans in financing sustainable development projects worldwide. A case study will be used to illustrate the principles and practice of green bonds and the critical success factors through a comprehensive literature review.

INTRODUCTION

In the quest to mitigate the effects of climate change, the world should be united as a family in putting up concerted efforts. Stemming from sustainability considerations for our own benefits, those of our neighbours and our generations to come, measures include the implementation of effective policies and regulations, technological innovations and a genuine desire to make good use of them.

For climate change mitigation and adaptation projects, capital expenditure is often a bottle neck, since conventional investors usually regard those projects as having high risk for securing their returns. In the debt market, although project finance is a possibility for some well structured projects, bank loans are not so forthcoming for projects which are not generating cash streams for repayment due to the benefits of climate mitigation being intangible in many instances, especially in the short term.

Whilst some countries have used bonds in financing their infrastructure projects which have environmentally friendly elements, their use is ad hoc and depends on the market conditions as to whether they are conducive to the issuance of bonds. Such conditions would include the prevailing market interest rates (a low interest rate environment favours bond issuance since pricing can be higher due to competition), the risk appetite of investors, credit ratings, liquidity of secondary market, etc.

Comparing between bank loans and bonds, the former offers more flexibility in terms of issue size, timeliness, negotiability and involves less transaction cost (Hyun et al, 2008). Yet, the nature of infrastructure projects means that long pay-back periods are entailed, which suit the longer maturity periods of bonds. The Asian Financial Crisis also revealed the vulnerability of the loan market and hence the financial system if over-reliance is placed on bank financing by all businesses. Hence, most governments would try to promote their domestic bond markets. Multi-lateral agencies (such as the World Bank and the Asian Development Bank) have been issuing bonds to aid the development of infrastructure in developing countries. In the private corporate sector, real estate developers may tap into the use of bonds to widen their financing channels (Lam et al 2011a), in addition to borrowing from banks and using their own retained earnings.

In the US, municipal bonds have been used to finance green infrastructure on a local basis for a long time. In the last 20 years, massive energy efficiency upgrading works for public facilities were carried out. Sometimes, Certificates of Participation (financial documents entitling the investors to revenues associated with leased installations, instead of interest and capital repayment) are issued by local governments. An example is the school board (an unrated issuer) of the city of Newport News, for which placements of US$12,480,000 were made in 2003 for implementing energy conservation measures based on the credit quality of the city government in the State of Virginia (Palatucci, 2008).

More recently, the terms “green bonds” or “climate bonds” have become better known than their predecessors.

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GREEN OR CLIMATE BONDS

Definitions

"Green bonds" are tradable debt securities with contractual repayment terms (such as interest rates, maturity periods, etc.) fixed at issuance, which are aimed at financing investments with environmental benefits or for the reduction of vulnerability to environmental changes. "Climate bonds" are similar but focused on investments for mitigating or adapting to climate changes (CDC Climat Research, 2012).

A New Asset Class

Green or Climate Bonds are theme bonds (similar to the railway bonds of the 19th century, the war bonds of the 20th century, etc.) to address environmental needs.

Institutional investors (such as insurance companies and pension funds) are increasingly looking forward to long-dated, low-risk and fixed income instruments to build up their investment portfolios. In parallel, environment concerns have grown day by day. As for the reduction of green house gas (GHG) emission, it was estimated that US$46 trillion would be needed for halving global emissions by 2050 (OECD and IEA, 2011). Low-carbon infrastructure has the characteristics of high capital cost and low operating cost, but mostly predictable revenue streams. Bond financing suits these characteristics, and thus can fill the finance gap (Sustainable Prosperity, 2012).

As in 2012, up to US$7.2 billion Green or Climate bonds have been issued with an environmental mission, mostly by multilateral agencies. The risks and returns of these new assets are getting closer to the conventional bonds, but unlike them, many green or climate bonds are not linked to the credit or performance of the projects. Investors do not assume the specific project risks (Sustainable Prosperity, 2012).

Investors' Interest

Facing the threat of climate change and the increasing price and security threats of energy supplies, a significant number of governments and institutional investors are shifting funds away from investments regarded as detrimental to the environment. As the development of green technology becomes more mature, the returns of green businesses are getting more stable and show an increasing trend. Business models of renewable energy and energy improvement works are more robust. Credit ratings are becoming more favourable. Investors are thus attracted to Green or Climate Bonds as a new asset class. Nevertheless, the size of green bonds issued to-date still dwarfs the overall global bond market size of US$95 trillion in 2010 (Sustainable Prosperity, 2012)

Policy and Institutional Framework

As mentioned, governments wish to widen the channels of business financing to avoid over-reliance on bank loans. On the environmental front, governments also want to see the increased use of private funds apart from taxpayers' money to implement green measure and put in place green facilities for use by the public.

International treaties (such as the Kyoto Protocol) or national policies are adding pressures to the developed world to reduce their GHG emission or pay for excesses beyond their committed reduction targets through emission trading schemes. The increasing awareness of corporate social responsibility also has a part to play.

In the UK, for example, calls are being made on the government to show its serious commitment to tackle climate change by designing green gilts (Veys, 2010).

In the US, the Energy Policy Act of 2005 enabled special tax concessions on bonds related to qualifying energy projects with an upper issue limit of US$2.2 billion as in 2009 (Veys, 2010). Secruitisation of payment streams from governmental agencies on energy improvement leasing schemes was made possible by adaptations of the regulatory framework to suit the realities of the capital markets (Palatucci, 2008).

In Canada, lobbying is being carried out for a government-backed green bond designed to engage the public by raising funds to accelerate the use of renewable energy (Action Canada, 2008). As at June 2012, the issuance of Green Bonds have yet to be materialised (Sustainable Prosperity, 2012).

In Asia, the ADB has sold the second lot of US$339 million of clean energy bonds to Japanese retail investors in 2012 (Bakewell, 2012) after its first launch of US$232 million to supports renewable energy and energy efficiency projects in Asia and the Pacific two years ago (Young, 2010).

Success Factors for Business Models

Lam et al (2011b) expounded on the critical success factors for bond financing of construction projects. For retail tranches, these include the mitigation of credit risks, enhancement of yield, liquidity and transparency, whereas for institutional investors, matching of asset and liability durations are important business considerations.

Additionally, for Green or Climate Bonds, it is imperative that tax incentives and guarantees are in place, both for the issuers and investors (as qualifying debt for interest tax exemption or rebate). Monoline insurance may help to reduce the apprehension on issuers' default, but the financial health of the insurers needs to be monitored, as lessons are learnt from the US Sub-prime crisis. It is also of paramount importance for the continued monitoring of the use of funds on environmentally beneficial projects. At the point of bond purchase, investors may need to ensure that the contractual clauses address this issue, as the bonds are theme-based. To this end, credit rating agencies may take this factor into consideration in their bond rating and keep monitoring it for possible downgrading in case the funds are misused. Until this can happen, some guiding framework such as the Climate Bond Standard, as being proposed in California, may be adopted to assure investors that their funds are contribution to the delivery of a low carbon economy (The Climate Bonds Initiative, 2011).

If the business model can be structured in such a way that the repayment of the capital and interest to the investors does not rely on the proceeds arising from the projects themselves, but linked to the financial performance of a broad range of best practice green corporations (as can be seen in the Case Study), the perceived risk of unsatisfactory performance of the specific projects may be reduced.

The size of issue depends on the market appetite, the funding requirement, the transaction cost (in terms of due diligence and distribution cost, etc.), the number of tranches (with different maturity periods), and the amount of carbon reduction being targeted at as well as phasing. If an issuance programme can be established instead of bespoke issues, transaction cost and time can be saved from the regulatory perspective.

The success factors or otherwise can be demonstrated through a case study approach, which can illustrate the planned aspects and contingency arising.

CASE STUDY

The case study presented in this paper is one of the first Climate Awareness Bonds (CAB) issued by the European Investment Bank (EIB) to form a pool of funds for lending to projects of climate change mitigation, including renewable energy and energy efficiency upgrading. It is chosen for study since it has reached maturity and the life cycle aspects can be evaluated for discussion purpose.

Background

In 2007, the European Union established a target of achieving 20 percent of energy from renewable sources by 2020, as well as saving 20 percent energy by the same year. Buildings account for 40 percent of the EU's energy consumption. The rest is from transport and other industries (European Commission 2008). An Emissions Trading Scheme (ETS) has been operative since 2005 in the EU for carbon reduction through trading of monetised allowances to meet committed targets amongst participating countries.

The Bond Issue

The issue was made in June 2007. The minimum issue size was fixed at EUR 600,000,000 with a single maturity period of 5 years (maturing on 28 June 2012). It was a zero-coupon bond with 100 per cent issue price at a par value of EUR100 each, although a re-offer price of 97.25 percent was made to institutional investors and distributors (http://kbl-archiv.boerse-stuttgart.de/prospekte/description/A0NWU1.pdf). The net proceeds of the bond issue were aimed at lending for projects of renewable energy and energy efficiency. Before such disbursement, the portfolio created would be invested in money market instruments.

The bond was unsecured and unsubordinated, carrying a rating of Aaa/AAA/AAA by Moody's, S & P and Fitch respectively. A secondary market was created by three bookrunners.

Whilst the repayment of capital was guaranteed, the return upon maturity was fixed at a minimum of 5 per cent or higher, depending on (1) a participation rate (between 75 to 80 percent as determined by the Joint Lead Managers in agreement with EIB on the pricing date) and (2) the proportionate difference between the values of an index named as the "FTSE4 Good Environmental Leaders Europe", by comparing the respective values of the index at the initial issue date and the maturity date. Instead of a spot index, the index at maturity was averaged from the index values for the last 7 months before maturity. As such, it was an equity-linked bond which was independent of the projects using the fund but linked to the total return performance of 40 best practice corporations in Europe in terms of environment-friendliness.

An important feature of the issue was that investors had the option to purchase carbon allowance through the ETS if they had overall return in excess of 25 percent upon maturity of the bond. As such, those willing investors could help to cancel the allowance existing in the emission trading market then with a view to enhance emission reduction.

Bond Performance

There was little change in credit rating throughout the 5-year bond life. There were also minor fluctuations in bond price, with a price at maturity of EUR 99.98 (Knowledge.Reuters, 2013). However, the relevant index did fluctuate from around 110 in 2007 to around 85-95 in 2012, when the bond matured. There was a significant drop around 2009 during the Sub-prime crisis and some falls also occurred in 2011 and 2012 (FTSE Group, 2013) due to the European debt crises.

The minimum Yield to Maturity (as on 21 June 12) was -99.939 percent and the maximum yield during the bond life was 0.429 percent on a daily basis in 2010. The terminal yield spread was -9996.3 basis points against a benchmark yield of 0.024 per cent from the Treasury (Knowledge.Reuters, 2013). Secondary market trading was not particularly active since most investors held the bonds to maturity.

Looking at this set of results, it is believed that the investors only got the promised minimum 5 percent return on their capital, which was not bad in light of the financial turmoil which Europe went through. The expected carbon reduction purchase might not have been materialised, but the funds were indeed used for climate and energy related projects. This temporary setback did not deter the EIB from issuing further CABs and many more issues have been launched successfully to-date, indicating good investor appetite.

CONCLUSION

Climate change mitigation and adaptation efforts do require substantial capital outlays, which can be met partially by government subsidies, carbon tax, emission trading proceeds, bank loans, corporate or public investment and the issuance of structured financial products such as Green or Climate Bonds. Although it cannot be certain that each bond issue would achieve its full intended purposes from the perspective of issuers and investors, as shown in the mentioned case study, the financing approach is a good lesson for regions (such as Asia) which share the same mission of climate change mitigation and adaptation. It is recommended that the success factors as mentioned be adhered to in the structuring of such financial instruments and diligent monitoring should be indispensable to ensure the sustainability of intended green development.

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The authors and the publisher do not guarantee the accuracy of the data presented in this paper, which is meant for academic discourse and not for commercial purposes.

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GREENROOFS IN SINGAPORE: HOW GREEN ARE THEY?

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ABSTRACT

Green roofs are more common in the tropical climate of Singapore compared with the other eco-roof types partly due to the government incentives. With limited natural resources and land, Singapore is unique, as most system components for green roofs are imported while waste is incinerated. However, the focus of green roof studies in Singapore setting so far has been the in-use performance benefits in terms of cost, energy and water savings without considering the lifetime performance. The decision to promote any strategy nevertheless needs to consider resource costs as well as benefits.

This paper discusses results from a life cycle study of common green roof types used in Singapore. The results suggest that environmental performance, evaluated using energy and carbon footprint, depends on the construction details and system components employed. The end-of-life waste disposal significantly affects the overall performance, and even with system expansion to include avoided electricity generation because of waste incineration, green roofs lead to an increased carbon footprint.

Keywords: green roofs, life cycle assessment, carbon footprint, tropical climate, Singapore, energy, cost

INTRODUCTION

Three types of eco-roofs; green (living), blue (water managing) and white (heat reflecting), are commonly used in urban locations to moderate the effects of climate change, such as extreme rainfall and temperature. A green roof is a conventional roof covered with a layer of vegetation, while a blue roof stores water using flow controls, such as downpipe valves, gutter storage systems and cisterns. A white or a cool roof maintains a lower roof temperature, compared to a traditional roof, by reflecting heat away using white paint or reflective coatings. The benefit of white roof is limited to temperature modifications while both green and blue roofs can in addition provide storm water management. In addition to these, green roofs provide biodiversity through habitat creation, improve air quality, and sequester carbon (Getter et al. 2009).

Singapore is a thriving world-class urban centre facing land and resource constraints. However, Singapore boasts a high level of greenery due mainly to meticulous planning over decades. Government goals under the Singapore Sustainable Development Blueprint (Ministry of the Environment and Water Resources and Ministry of National Development 2009) includes, making optimum use of land while ensuring green space is maintained at $8m^2$/person, and increasing greenery in high-rise buildings to 50ha by 2030. Currently, green roofs are more common in the tropical climate of Singapore compared with the other eco-roof types due partly to the government incentives introduced under the Skyrise Greenery Incentive Scheme. Since its inception in 2009, this scheme, which provides up to 50% of the installation cost of green roofs (and green walls), has funded over 200 developments.

Local and international research has already established performance benefits of green roofs in different climate zones (Alexandri and Jones 2008; Fioretti et al. 2010; Parizotto and Lamberts 2011; Voyde et al. 2010; Wong 2002) and building types (Castleton et al. 2010; Santamouris et al. 2007; Whatley 2011; Wong et al. 2003a). The focus of local research seems to be on the in-use performance benefits without considering the resource costs involved in establishing, maintaining and end-of-life disposal of these systems. The limited international studies that do consider lifetime performance have highlighted the need to find alternatives with lesser environmental impact to those green roof materials in current use (Bianchini and Hewage 2012). This may be especially applicable in Singapore where all materials/components used in green roof projects are imported while waste is incinerated. Therefore, prior to promoting wider uptake of green roofs through incentives a holistic evaluation that considers resource costs as well as benefits accrued over the lifetime is needed.

Khoo and Mithraratne (2012) in a study comparing the relative performance of blue and green roofs in Singapore concluded that green roofs are better in terms of environmental and financial performance even with a long-term perspective. However, the current blue roof projects in Singapore tend to be limited to retention type incorporating large water bodies for their architectural merit, and the relative environmental performance of detention type blue roofs could be somewhat different to these. Furthermore, the above study considered only limited green roof types, while excluding the maintenance

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requirements. The thermal simulation software used for that study (*EnergyPlus*) could not simulate true properties of water bodies, and therefore the effect of both green roof and water body was limited to a mass layer neglecting the effect of soil moisture on the thermal benefit of green roofs. While, soil moisture could increase thermal conductance, plant shading could reduce the solar gain and the roof surface temperature.

This paper presents the results of a life cycle assessment study of alternative green roof systems commonly used in Singapore with concrete roof slabs. The benefits from green roofs cover a broad range; both qualitative (improvements in habitat and urban air quality, reduction in noise and urban heat island effect) and quantitative (reduction in storm water runoff and energy use in buildings, and carbon sequestration). Stovin et al. (2012) have highlighted difficulties in quantifying the stormwater benefit, while carbon sequestration has been estimated to be negligible (Getter et al. 2009). Therefore, this paper is limited to implications on the building energy use. The indicators selected to denote lifetime environmental and financial performance are, energy and carbon footprint, and payback period. The paper structure is as follows. First, the life cycle assessment undertaken is outlined, along with the green roof systems considered and assumptions used. Results, on relative performance, are then presented, and conclusions are drawn.

ALTERNATIVE GREEN ROOF OPTIONS IN SINGAPORE

Green roofs can be classified using maintenance requirements (extensive, semi-intensive and intensive) and construction methods (continuous build-up or modular). Accessible, intensive green roofs, also known as roof gardens, are more common in Singapore compared with extensive roof gardens, which are inaccessible. While roof gardens are built on-site layer by layer and therefore continuous in construction, extensive green roofs can be either build-up or use modular systems that generate an instant effect. The modular construction system provides easy access to the roof structure in case of water damage or alternative roof use at a later stage compared with the build-up system and therefore could be more attractive in certain situations. However, the resources out lay of the two systems, modular and continuous, vary widely.

To assess the lifetime performance of green roof options used in Singapore, three green roof systems are considered; continuous extensive, modular extensive and continuous intensive. The construction, maintenance and end-of-life disposal scenarios of these systems are discussed next.

Construction

- *Continuous extensive green roof system*, with 100mm thick substrate layer and ground cover plants covering 100% roof area
- *Modular extensive green roof system*, with light weight polypropylene tray system, 70mm thick substrate layer and ground cover plants covering 100% roof area
- *Continuous intensive green roof (roof garden) system*, with 700mm thick substrate layer, 80% of the roof area covered with shrubs (roughly 0.5m high) while the rest is covered with ground cover plants

Maintenance

Extensive green roofs require weeding, pruning and fertilising three times a year, while around 10% of the plants need to be replaced annually. Regular maintenance, the frequency of which could vary from daily to fortnightly depending on the building, is necessary for intensive green roofs while plant replacement is also higher at about 20% per annum. Due to higher fertiliser demand and frequent stability and pest attack tests of shrubs, a part-time gardener would also be necessary.

End-of-life

The end-of-life waste disposal practices for green roofs are not established in Singapore. The waste handling scenarios suggested by industry sources varied from one supplier to the other. While it is likely to reclaim the drainage layer and substrate materials, the low value products of the remaining layers mixed with dirt are likely to be sent to landfill. The plants and plant media removed are likely to be taken back to the nursery for composting and re-use, respectively. Although the plant tray (with a 5─6 year useful life) can be re-used, currently trays are sent to landfill once removed.

LIFE CYCLE ASSESSMENT STUDY METHOD

The study involved two main steps. First, a streamlined life cycle assessment (LCA) was conducted of the three systems identified using industry data on material sourcing. The indicators selected for this LCA are, energy, greenhouse gas emissions and cost. The system boundary extended from acquiring the raw materials, producing the green roof materials, transporting the materials to the construction site, constructing the green roof, maintaining the green roof to disposing the waste materials at the end of the life span for the three strategies. It was assumed that the green roofs are established on a 5-storey hypothetical office building with a 1000m^2 roof area. The LCA is limited only to the parts of the building and roof that are affected by the change in materials across the roof types.

Then, the annual energy requirement of this office building located in Singapore, to maintain 24°C internal temperature between 7am and 9pm during the weekdays, was simulated using *EnergyPlus* 7.2 (Crawley et al. 2001) thermal software. An exposed roof with a PVC water proofing membrane was used as the base case, and the relative overall benefit of green roof systems in reducing the cooling energy requirement was estimated. The benefit of cooling is considered to be limited to the floor space directly beneath the green roof.

ASSUMPTIONS

The assumptions used to facilitate the assessment with respect to resource use and energy benefit are as follows.

Useful life

Green roofs are a recent development in Singapore and therefore the useful life in local conditions is not established yet. Useful life depends not only on the technical aspects but also on the economic considerations such as the demand on limited land. In previous studies, Kosario and Ries (2007) used 45years as useful life in the USA while Wong et al. (2003b) used 40years in Singapore. Considering that the buildings in Singapore are demolished long before the end of their useful life, to accommodate changing building demands, a shorter useful life of 20years is used in this study.

Modular tray

Trays used in the modular construction system are produced in Singapore using recycled polypropylene. Although the use of recycled plastics eliminate the resource use associated with oil extraction and polymer manufacture, the resource cost associated with recycling and recovery process needs to be included. Data on recycled polypropylene tray manufacturing process in Singapore, are not available. Therefore, for production of recycled polypropelene pellets, inventory data from literature (Vidal et al. 2009) are used with current Singapore specific waste management practices (National Environment Agency 2002) and electricity data (Tan et al. 2010). Resource requirements for plastic moulding have been added to this based on ecoinvent data modified to represent Singapore grid electricity. It is assumed that the trays are replaced at 5-year intervals.

Origin of materials and components

Most materials used in green roof systems such as drainage layers, filter layers, substrate and plants are sourced from overseas. Although the substrate composition can vary from one green roof supplier to the other, main ingredients are, recycled construction waste (bricks/clay tiles), pumice, minerals and organics. Substrate materials are predominantly sourced from Malaysia and Indonesia. Seedlings grown in polyethelene bags generally come from Malaysia. Green roof drainage components, filtering and roof protection layers used in Singapore are mainly sourced from Germany.

Transport

For imported products and materials, land transport within the source country, shipping to Singapore, and lorry transport within Singapore are included. It is assumed that the return trip for land transport is empty while ships carry other goods on their return journey. A 25km distance by lorry from green roof site to supplier's yard and from yard to waste management facility at the end of useful life is also included (Tan and Khoo 2006).

Waste management

The following scenario was used based on suppliers' data. All materials and components removed are transported to the supplier's yard. The drainage layer and substrate material are reclaimed for re-use, while the rest of the under layer products and modular trays (except drainage system) are transported to waste management facility. It is assumed that 10% of drainage layer (due to odd-sizes) and substrate material are also sent to waste management facility. At the supplier's yard, plants are composted and plant media is reused.

DATA SOURCES

Embodied energy and CO_2 emissions of drainage materials, filtering and roof protection layers are based on *ecoinvent* 2.1 data. The gaps in LCA data were filled with literature sources (Ledgard et al. 2011; Vidal et al. 2009). These are limited to recycled polypropelene and fertilisers. The overseas data were modified to reflect the respective local practices and conditions.

All diesel vehicles used in Singapore are assumed to conform to EURO 4 emissions standards (Silitonga et al. 2012) and modelled using ecoinvent data. Data on production of fertilisers are based on European practices from literature (Ledgard et al. 2011). Transport (shipping) of fertilisers from Europe to Singapore has been included.

The main ingredient in substrate is recycled construction waste. The substrate resource use is therefore considered to be limited to transport (shipping and road transport). Resource uses for plants are considered to be limited to polyethelene bags and road transport.

Installed cost of green roof systems and components were sourced from industry sources. Any savings in cooling energy requirement is considered to be a saving of average grid electricity in Singapore with a

unit cost of 28.57cents (SP Services 2013). Since its impossible to forecast the likely inflation rate over the next 20years, which is the evaluation period, the life cycle cost is calculated using real costs (inflation excluded), using current prices for green roof components and electricity, at a discount rate of 5% and constant prices. The life cycle cost thus established represent the present value of the total amount that needs to be set aside today to maintain the green roofs over the 20-year evaluation period.

RESULTS

Energy and carbon footprint of green roof systems

The energy and emissions associated with the three green roof systems considered are shown in Figure 1 and 2, respectively.

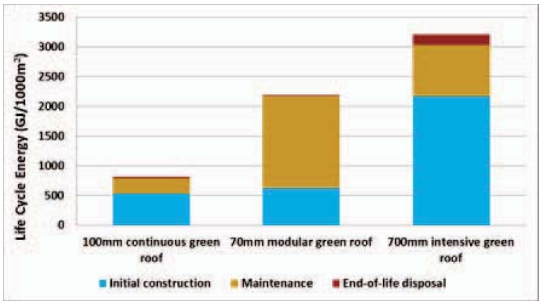


Figure 1 – Lifetime energy of common green roofs in Singapore

In terms of relative performance, lifetime energy of modular extensive green roof system is about three times that of continuous extensive green roof while the intensive green roof system is four times that of continuous extensive green roof. The total emissions associated with different green roofs systems follow a pattern similar to life time energy, with emissions of modular extensive and intensive green roofs being three and five times, respectively compared with those of continuous extensive green roof.

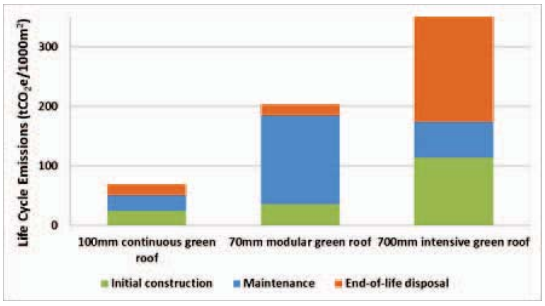


Figure 2 – Lifetime carbon emissions of common green roofs in Singapore

The results indicate that the life stage responsible for the majority of energy use or carbon emissions depends on the green roof construction system; continuous or modular. For continuous construction, the majority of energy (over 65% of the total) and emissions (over 70% of the total) are a result of initial construction, irrespective of whether it is an accessible or inaccessible green roof. For modular construction system however, the maintenance is responsible for 71% of total energy use while also releasing 73% of the total emissions. This could be expected due to the short useful life of the tray, even though the trays are produced of recycled polypropylene in Singapore.

However, whether green roofs are environmentally prefereable would depend on the energy savings that may be accrued over the lifetime, and whether the energy and emissions saved over the 20year life out weigh the energy and emissions embodied in the systems. The total lifetime energy of the three green roof systems including the reduction in cooling energy requirement as a result of green roof (relative to a bare concrete slab roof) is shown in Figure 3.

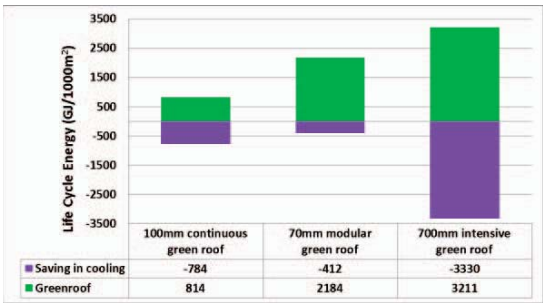


Figure 3 – Lifetime energy of common green roofs in Singapore including cooling energy savings

During the 20-year useful life considered in this study, only intensive green roof system pay off the energy invested in the green roof as electricity savings. While the cooling energy savings represent 96% of energy used by continuos extensive green roof, it is only 19% of the energy used by extensive modular tray green roof.

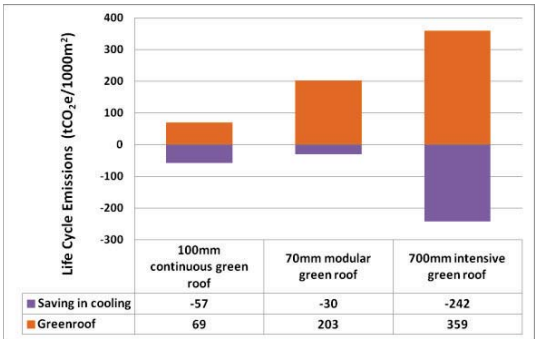


Figure 4 – Lifetime emissions of common green roofs in Singapore including cooling energy savings

If the emissions are considered, none of the green roofs avoid sufficient emissions as electricity savings to pay back the emissions associated with the green

roof system. The emissions savings due to cooling energy reduction are only 82%, 15% and 67% respectively for continuous extensive, modular tray and intensive green roof systems (see Figure 4).

However, as main waste management method in Singapore is incineration, any waste generated as a result of establishment, maintenance and end-of-life disposal of green roof system components can avoid electricity generation using other fossil fuel sources. Therefore for a true evaluation of the performance of green roof systems, the system boundary should be expanded to include the avoided electricity generation.

Once the system boundary considered for green roof systems is expanded to include the waste-to-electricity generation, both continuous extensive and intensive green roof systems, save more energy than invested in the system over the 20-year lifetime (see Figure 5). However, the modular tray system performance improves only marginally, with 20% of the lifetime energy recovered during the 20-year period as energy savings.

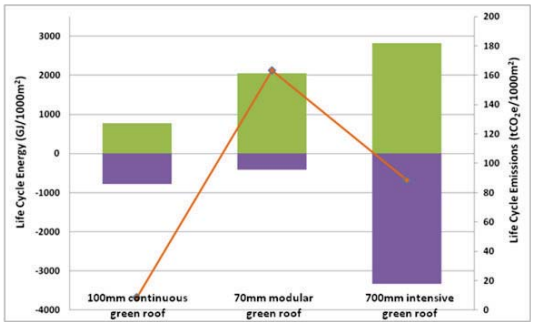


Figure 5 – Lifetime energy and emissions of common green roofs in Singapore including avoided electricity generation

However, none of the green roofs avoid sufficient emissions as electricity savings to pay back the embodied emissions. Both modular and intensive green roofs generate significant emissions burdens at 163kgCO_2/m^2 and 89kgCO_2/m^2, respectively. This is to be expected as, waste-to-electricity generation, is over 3.6 times emissions intensive compared with the curent gird electricity (Tan et al 2010), although lower in energy intensity.

Financial performance of green roof systems

The life cycle cost of the three green roof options, which includes initial cost, maintenance and energy savings, is shown in Figure 6. While the continuous extensive roof is 8% higher in initial cost compared with modular roof, it is lower in maintenance expenditure while achieving higher energy savings. If the 20-year cost is considered both continuous and modular extensive green roofs are similar. With the government incentive of 50% of the total cost of the construction included, the absolute costs of the systems are lower but the pattern remains the same. However, the cost of electrcity could increase over time and this has not been considered in this evaluation.

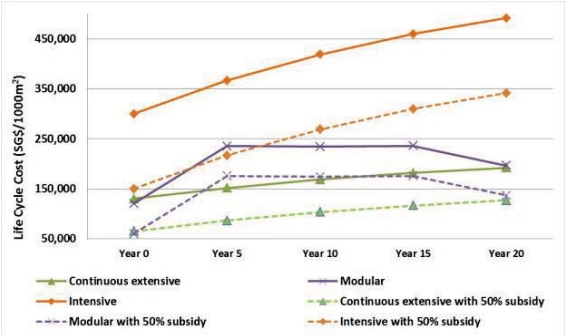


Figure 6 – Additional cost of common green roofs in Singapore with and without incentives

CONCLUSIONS

The results reported here, based on quantifiable benefits of green roofs, suggest that environmental performance of green roof systems depend on the typology and components used. However, as an emissions reduction measure none of the current typologies used in Singapore are effective. In terms of life cycle cost, the green roof systems do not seem to pay back the initial investment, although it could provide a safeguard against future price increases in electricity. In any case, overall benefits of green roofs extend well beyond the energy benefit considered in this paper.

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LOCAL; GLOBAL; HYBRID: DEVELOPING A DISCURSIVE FRAMEWORK FOR HYBRIDIZATION

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ABSTRACT

An increasing number of professionals and academics have started to realize the notion of viewing the built environment as a holistic framework. A 'framework' can be defined as a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality. Within this conceptual framework, analysing the conditions of contemporary building practices raises a series of questions: What are the impacts of global culture in the built environment?; How could vernacular building cultures serve as useful models that could inform contemporary building practices in the tropics? How could vernacular and global building cultures become mediated? And so on. This paper suggests hybridization of two seemingly disparate realms of building i.e. the *vernacular* and the *global.* Historical analysis reveals that they interestingly share some common ground. Six conclusive logics emerge and become formative elements of a new hybridized building system.

INTRODUCTION

People's aspiration to modernize and relate to contemporary social and cultural values has led them to receive globalization in the place of modernization. It appears to me that the confusion arises due to similarities in their expected outcomes. Among professionals, there is a sense of urgency to remain updated and stay at the cutting edge of global technological innovation regardless of their intended outcomes. On the other hand, indigenous or locally developed systems have been constantly threatened and displaced by global influences. The sustainable processes that are embedded in indigenous systems are rarely appreciated and utilized. Globalization and Capital Culture tend to be barriers to sustainable development due to their impact on people's consumption patterns. Local systems and technologies are increasingly appearing unattractive when compared to their global counterparts.

Global Culture and Architecture

First appearing in Webster's Dictionary in 1961, the term 'globalization' has since become increasingly used in various fields. Global culture could be expressed as a phenomenon relating to the "worldwide interconnectedness of social events and relationships" (Rieger-Jandl, 2006, p. 16). The exponential growth of the world economy in the second half of the 20th century has been attributed to globalization. Robertson (1992) defines globalization as a process by which "the world becomes a single place" (p. 135). Global culture is part of the contemporary discourse on 'globalization'. King (2004) suggests that the term 'global' has been referred in a consciously metaphoric way as that which is all inclusive or universal. He adds that the notion of global architecture and building culture is one example of the many impacts of global culture. Since the 1990s, the phrase 'global culture' has become commonplace in public spheres and academic institutions, raising concerns as a concept and building practice. It is also important to note that global culture may also represent something that has existed for a long time in various other forms and names: cosmopolitanism, internationalism, universalism, etc. Globalization, as a discourse recognizes a shift in world order and has considerable influence on various other fields. Robertson (1990) argues that the study of globalization and global culture as a phenomenon requires interdisciplinary treatment and depends on historical and comparative disciplines. Hence the impact of globalization and global culture on architecture and building are unavoidable and at the same time comparable to many other disciplines.

Vernacular Building

The study of vernacular architecture is considered to be part of the larger scholarly undertaking of Material Culture (Schlereth, 1985). The field incorporates many perspectives and ideas about what it is composed of. Paul Oliver (1997), considered by many to be one of the pioneers of vernacular architectural studies, observes that the field like most other disciplines is a realm of inquiry that is continuously evolving and changing. However, Oliver (1997) notes that the study of vernacular architecture has achieved some stability in terms of patterns and conventions. Broadly defined, 'vernacular' refers to the language or dialect of a country or region. This definition when applied to the local building culture derives a metaphoric appropriateness. Vernacular derives from the Latin word *vernaculus* meaning 'native'. There is a general assumption that vernacular architecture implies to that which is indigenous to the country and not borrowed, or learned from. Yet, Oliver (1997) finds the idea of being 'not borrowed' or 'learned from' to

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be open to argumentation. Carter & Cromley (2005) define vernacular architecture as "the study of those human actions and behaviors that are manifest in commonplace architecture" (p. xiv). Buildings help generate a set of forms and patterns that provide information about human behavior in the past and the present. More recently, Nezar Al Sayyad (AlSayyad, 2006) has offered a more dynamic definition. He argues that vernacular has traditionally been defined as a concept rooted in place, "produced without the need for imported components and processes, and possibly built by the individuals who occupy it" (p. xvii). In the twenty-first century, he observes, "as culture and tradition are becoming less place-rooted and more information-based, these particular attributes of the vernacular have to be recalibrated to reflect these changes" (AlSayyad, 2006, p. xvii).

THE NEED FOR NEW STORIES: HYBRIDS

In their recent work titled 'Hubris and Hybrids', Mikael Hard and Andrew Jamison (2005) talk about the process of 'cultural appropriation' as an approach in the historical analysis of science and technology. The process of cultural appropriation, they argue, is "by which new things and new ideas are made to fit into established ways of life" (Hard & Jamison, 2005, p. 4). In this view, they argue that there is possibly an "additional set of stories that need to be told, the ones about using, learning, interpreting and giving meaning, which follow story lines of appropriation" (Hard & Jamison, 2005, p. 4). Cultural appropriation is defined as a process in "which novelty is brought under human control" (Hard & Jamison, 2005, p. 4). In other words, it could be viewed as a concern to re-create human and social values in order to make sense of new ideas and products. They argue that the world around us is composed of different practical skills and knowledge systems, social roles and competencies, visions and practices that are constructed by human life. The storylines of appropriation are those of combinations and compositions. In other words, they are logical narratives of hybridization that are composed of practices, institutions and discourses. However, it is important to note that 'appropriation' is not a recent or newly invented conception. Hard and Jamison (2005) provide historical references where appropriations have happened in the form of mediating devices. Societies have often acquired new identities and altered their needs in order to make use of new scientific and technological developments. Similarly, Jandl (2006) argues that contacts between local and global forces have often resulted in the "hybridization of collective identities and struggles over representation" (p. 57). She argues that 'colonization', which preceded globalization, had a similar impact on the local culture resulting in the formation of hybridized identities. Exploring the possibilities of this increased cultural interaction might provide opportunities for creative and productive transformation of the built environment.

This paper argues the need for hybridization as an intermediary platform where the values of indigenous systems and the benefits of global systems can possibly be integrated. The need for new narratives about cultural appropriation and hybridization is imminent. Having stated the need for building an intermediary platform, it is important to define the context of this proposed hybridization. In other words, the hypothesis of hybridization needs to be situated in the realm of architecture and building. It is also important for this proposed hybridization to be applicable in the larger context of building as a process.

THE CULTURE OF BUILDING

In recent times, there has been a renewed understanding about the importance of building processes as opposed to the objective qualities of buildings themselves. An increasing number of professionals and academics, like the author of this paper, have started to realize the notion of viewing the built environment as a holistic framework. Howard Davis (1999) coined the term 'Building Culture' in an attempt to define this holistic framework. A 'framework' can be defined as a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality. Davis (1999), in his book titled 'The culture of building', argues that the process of building could be understood as "a coordinated system of knowledge, rules, procedures, and habits, related to a particular place and time and collectively referred to as *the building culture*" (p. 3). Building culture explained in this way, describes the character and form of the huge number of 'everyday' buildings, in addition to the individual and well-known buildings. It is a collective phenomenon that represents thousands of different buildings that are produced through shared processes and shared knowledge. The construction of a building is embedded in a perceivable pattern of human relationships between many participants such as contractors, clients, building users, architects, building officials, surveyors, materials suppliers, manufacturers, and so on. This pattern of relationships on the other hand is characterized by the predictable ways in which people do their jobs and tend to relate with each other.

Building Culture as a Framework

Builders and architects tend to have a general understanding about the various components of the built world, taken individually. This may range from knowledge about architectural styles, prices of

building materials, zoning regulations and so on. However, Davis (1999) argues that what is not available is a "general framework of thought in which all of these things are related - a framework in which the process of building production as a whole is understood in terms of the various components that make it up" (p. 3). This framework is necessary to understand that the building culture is not the outcome of any one profession, such as architecture. The product of the building culture is the built world of more than two billion buildings, both the 'everyday' and the 'monumental': houses and warehouses, religious buildings and theatres, libraries and schools, offices and factories. Architects, on the other hand are responsible for less than 2% of all the buildings built in the world. Davis (1999) argues that large scale developments do not solely depend on the architects and city planners. Instead, they result from a "gradual transformation of the building culture shared by people who participate in the building activity" (Davis, 1999, p. 3). This understanding is important as it deals with the process behind the whole built world including the 98% of everyday buildings.

Building as a Unified Social, Cultural and Technological Process

Rather than individual phenomena that result from independent acts of creation, the 'building culture' is viewed as a framework that accommodates social, cultural and technological processes that are represented in the built form. Buildings are products of social-technical processes that differ in systematic ways from one place to another and from one time to another. These processes are unique to a culture and differ in significant ways from other cultures. For instance, the very need to build may vary largely based on prevailing socio-economic conditions of building cultures. Davis (1999) observes that the "understanding of process depends on seeing technology as a human system" (p. 13). But the word technology, he argues, is "sometimes interpreted to indicate something that is particularly modern" (Davis, 1999, p. 13). In other words, it is distanced from the artistic realm of human activity and considered to be purely associated with science. Davis (1999) contends that in a broader sense, technology refers to the "entire means of production and is not limited to tools and machines" (p. 13). In other words, it is not possible to understand the idea of 'technological change' outside the context of the people who are making and using it.

INTERPRETATION & LOGICAL ARGUMENTATIOIN

Within the conceptual framework of 'building culture', analysing the conditions of contemporary building practices raises a series of questions: What are the impacts of global culture in the built environment? How could vernacular building cultures serve as useful models that could inform contemporary building practices in the tropics? How could vernacular and global building cultures become hybridized and mediated? and so on? The proposed hypothesis of hybridization is based on historical and interpretive analysis of two seemingly disparate realms or processes of building i.e. the *vernacular* and the *global.*

Historical & Interpretive Analysis

Both Vernacular and Global building processes were examined with reference to Davis' framework of building culture. The analysis was confined to their importance as 'processes' and approaches to the culture of building. This analysis then forms the background for the proposed hybridization. In other words, the study of Davis's work generates an analytical framework which becomes useful in approaching the vernacular and global processes of building. The study and analysis chiefly drew from scholarly texts, research papers and journals. In addition, the analysis of Global cultures also depended on popular media, statistical data, and historical narratives to a certain extent. This is partly due to the wide-ranging cultural impact of Globalization and the lack of adequate and/or substantive research in the specific field of Global Architecture and Building.

Logical Argumentation

Historical and interpretive analysis of *Vernacular* and *Global* building processes yielded a set of logical conclusions. The process of logical argumentation was employed to derive conclusions from the analysis of vernacular and global building processes. Logical argumentation can be explained as a process that frames research outcomes into a new conceptual system or updates an existing system in response to changing conditions. Logical argumentation, conceived as a research strategy, is very powerful in being able to situate a large and diverse amount of extant literature into a single conceptual system (Groat & Wang, 2002, p. 334). The logical conclusions derived from the analyses form the basis for the proposed 'hybridization' and are summarized in the following paragraphs.

VERNACULAR BUILDING PROCESS: LOGICAL CONCLUSIONS

The analysis on vernacular building processes as discussed and argued by various scholars in the field is summarized as major conclusive logics in the following paragraphs. These logics represent a concise summary of recurrent themes addressed by various scholars to varying depths of inquiry.

Historical Negligence (Oliver, 1997)
Architectural history emerged during the late nineteenth century and grew steadily into a respectable scholarly discipline. But until the late 1960s books on architectural history were chiefly concerned with monumental buildings that were built all over the world. The study of architectural history, even today, is exclusively concerned about edifices such as palaces, churches, temples, mosques and great private mansions (Oliver, 1997). Schools of architecture are concerned with the great periods of art and architectural development and biographies of famous architects (Davis, 1999). There seems to be a general confinement to the study of what are perceived to be crowning achievements in the field of design from past to the present. The huge proportion of mankind's 'everyday' buildings are considered to be of little or no importance and overlooked in works of architectural history. Rudofsky (1964) argued that historians have obscured the talents and achievements of numerous anonymous builders and urged architects to look at the vernacular as the outcome of rare good sense in the handling of practical problems (p. 1).

Two Intellectual Traditions: Western and Non Western (Asquith & Vellinga, 2006)
Recently, many scholars have identified two distinct intellectual traditions of enquiry in the history of vernacular architecture: Western and Non-Western (Asquith & Vellinga, 2006). The 'Western' tradition of inquiry is largely concerned with the documentation and understanding of historical, rural and pre-industrial buildings. Some scholars refer to this as the 'English' model of vernacular research. This tradition is dominated by architectural historians, preservationists, folklorists and geographers. The implicit assumptions of this scholarly tradition acknowledge historic value of vernacular buildings while ignoring their active re-use and future adaptation. The 'Non-Western' approach on vernacular architecture is more concerned with non-western cultures, although it includes studies of western cultures as well. Studies that document vernacular building environments within their cultural and historic context are common in this discourse. Researchers analyze the complex ways in which the design, use and meaning of vernacular traditions change within contemporary processes of modernization and globalization. This tradition is more theoretically oriented and some scholars associate this approach with the 'American' model (Asquith & Vellinga, 2006).

Vernacular as a 'Reciprocal' Process (Oliver, 1997) (Bronner, 2006)
The vernacular process describes "buildings as social representations linked to coherent cultural systems of values and beliefs" (Bronner, 2006, p. 24). If buildings could represent the cultures that produce them, then it should also be possible to know how and why they are produced. People's values, ways of living, and ways of building are continuously transmitted and inherited. This understanding leads to what might be defined as Tradition. In this way, tradition enables us to examine social processes of creation and transformation. Bronner (2006) considers buildings as longstanding reminders of the resources and labor available in an environment.

Ethnography as a Tool (Carter & Cromley, 2005)
Ethnography, a branch of anthropology, is broadly defined as the scientific study of human culture. Buildings reflect our cultural values, as both agents and the products of culture. They become symbolic representations of cultural values. Anthropologists observe that the material world is responsive and architecture, a dominant product of the material culture, "possesses the dual characteristics of being both a product of social relations and a producer of social relations" (Gottdiener, 1994, p. xv). Similarly, Carter & Cromley (2005) observe that the process of the vernacular needs to draw answers from the act of satisfying people's needs. Architecture, they argue, in all its forms attempts to address specific needs such as of shelter, work, social identity, cultural affiliation, and aesthetic taste. Any single building solution would not be able to meet different needs and demands. But some buildings meet more demands than others and thus become consistently favorable for users and occur in large numbers all over. Carter & Cromley (2005) urge architects to behave as analysts in finding out as to "why some buildings become the best solutions" (p. 9).

Vernacular as a Model System (Rapoport, 2006)
The work of Amos Rapoport helps us to understand the 'relationship' between culture and the built environment as a conceptual framework. Rapoport (2006) contends that the primary reason behind his experiments is to learn from what the environment has to teach. Rapoport's proposal for developing an 'explanatory theory' is the principal characteristic that separates his work from that of the other scholars in the field. 'Rule systems', he defines, are sets of roles, ideals, goals, institutions and actions that are desirable or admirable in a particular culture. He observes that these rule systems are difficult to identify and argues that it is essential to generalize in order to be able to develop an abstract theory. He observes that vernacular environments provide the only possible 'laboratory' with a vast resource of human responses. According to him, this valuable resource is composed of both successful and unsuccessful solutions that might inform design. He suggests a more problem-oriented, conceptual approach to analyze the conditions in the field of vernacular design.

Availability of Ideas: Inspiration (Carter & Cromley, 2005)
Vernacular designers work from a commonly understood and shared ground of forms and materials that have been tested in a specific community over generations. In contrast, the professional architects, for whom originality is an important concern, draw ideas from various contexts and sources, local and global. The most important character that differentiates vernacular design is its dependence on the availability of local ideas. In comparison, the 'high-style' designers exploit the freedom to draw ideas from all possible sources. In vernacular building, there is a self-contained and limited range of ideas driven by community values or the intended audience and market. There is also the fear of violating conventional norms of the community if the building had foreign influences (Carter & Cromley, 2005).

Tradition and Transmission (Bronner, 2006)
In vernacular design, there is a widespread understanding that tradition tends to dominate, resulting in the restriction of choices (Bronner, 2006). Tradition has not been applied to building as an explanatory concept. This could be attributed to the fact that vernacular scholars have typically approached the building as an object rather than an event or process. 'Tradition', understood as a continuous and creative process that transmits values and beliefs, tends to shape buildings and reciprocally, buildings embody traditions (Bronner, 2006). Tradition as a system of reference to precedents is not fixed. In other words, Bronner (2006) argues that it is viewed as a system of socially shared knowledge and information transmitted across space and time. It is a social construction that is often renegotiated from time to time and from generation to generation in every community. Viewed in this way, tradition provides a framework that allows choice and adaptation.

Romanticization (Oliver, 1997)
Oliver (1997) argues that the vernacular, like other cultural constructs, results from the active interrelation between ecological and cultural factors. Hence it is important to note that vernacular settlements naturally require adaptation in order to be sustainable (Oliver, 1997). While acknowledging the achievements and qualities of the vernacular, it is equally important to identify its weaknesses and failures. A critical understanding should be developed without romanticizing ideas about its suitability or its superiority. There are historical references about vernacular environments and technologies that have failed for many reasons (Rapoport, 2006). These failures need to be reevaluated based on the current cultural and ecological circumstances. A general tendency to view the vernacular as naturally appropriate and sustainable should be questioned. Rappaport (2006) contends that a romanticized notion of the vernacular rarely provides useful lessons.

GLOBAL CULTURE & BUILDING PROCESS: LOGICAL CONCLUSIONS

Conclusive arguments resulting from the analysis of Global building processes are discussed in the following paragraphs. These arguments or logics represent a concise summary of recurrent themes addressed by various scholars.

Question of Replacement or Coexistence (Roberson, 1992)
Many scholars including Robertson (1992) have suggested that the idea of a global culture is in the process of becoming as meaningful as the local culture. The more important question then is whether it will replace or exist alongside of other non-global forms. In recent times, however, important considerations have appeared about the perception of humanity becoming unified into a single society in physical terms. In other words, globalization and global culture have generated a constant discussion about the fear and resistance of a possible re-organization of the entire planet (Rieger-Jandl, 2006). People are either consciously or unconsciously changing the world through their own perception of reality. There is a noticeable modification in the social institutions, living habits, the built environment, and many other domains either by intended or unintended acceptance.

General Conceptualizations of Global Culture (King, 2004)
Anthony King (2004) has collected and organized a sample of conceptualizations contributed by academics, journalists and others who have used the term 'global culture' or have written about it in detail:

- *Plurality and Spatialization-* An assortment of cultural artifacts or phenomena from different parts of the world in one location, previously not perceived as belonging there, but now so perceived.
- *The Deconstruction of the Nation State-* Set of practices, bodies of knowledge, conventions, and lifestyles which have developed in ways which have become increasingly independent of 'nation-states.
- *(American) Cultural Imperialism* - American media culture, commodities, fast food and malls are creating a new global culture that is remarkably similar on all continents.
- *'Homogenized' System of Culture* - A completely new system of culture emerging from the diffusion of many cultural values,

> beliefs, and practices worldwide. It takes on new attributes and becomes transformed in the process. (pp. 26-27)

Spatializing Global Cultures (King, 2004)
King (2004) argues term global is a spatial expression and is most closely associated to geography. They may either be 'centripetal' or 'centrifugal' flows. The 'centripetal' flows of global culture are characterized by cultural forms and practices that originate from various parts of the world. These flows become continually transformed, indigenized and adapted to the locality (Appadurai, 1997). They are manifested in one or more places or among a particular population, resulting in a process termed as 'Glocalization' (Roberson, 1992). On the other hand, the centrifugal flows of global culture are characterized by cultural influences and practices that emerge from one location or region historically and "are found, again in various indigenized or 'translated' forms, in many parts of the globe" (King, 2004, p. 29). In other words, the practices and influences are spread across the globe from one central source through different mechanisms and in different time periods.

Political Agency (Davis, 1999)
Throughout history, various social and political forces have been responsible for the creation of distinct identities in architecture. Looking at the history of architecture, distinct typologies of buildings were the result of various social conditions and subsequent revolutionary changes (Davis, 1999). In medieval times, these were the churches and religious buildings whereas in the nineteenth and early twentieth centuries architecture was largely promoted by imperial, colonial and national governments besides industries and companies. Most importantly, in the early twenty-first century, the most powerful promoters are multinational corporations, banks and international organizations that have led to a globalized and universal style of building. Davis (1999) argues that changing forms and identities in architecture are largely dependent on the success and failure of these promoters and patrons from time to time.

Global Culture as a Relational Interpretive Framework: (Appadurai, 1997)
Anthropologist Arjun Appadurai (1997) argues that global culture is better understood as a 'contrastive' rather than a 'substantive' property of entities. In other words, it could be regarded as a dimension of phenomena. He stresses that the 'dimensionality' of culture rather than its 'substantiality' enables the perception of culture as a heuristic device. It should be treated as a means to understand differences in identity as opposed to viewing it as an inherent property of individuals and groups. He contends that global culture could be approached as a relational interpretive framework.

The Concept of Identity (Rieger-Jandl, 2006)
The concept of identity can be understood in two ways. It describes individual expression of "self-identity", making a person 'different' from all others and at the same time 'unique' as an individual. In another sense, the term refers to a larger collective entity of "ethnic identity". This reference is usually attributed to the common values that people may associate themselves. Jandl (2006) argues that both individual and collective identities carry different meanings. Individual identity could be defined as a form of meaning created by a set of cultural attributes. Whereas collective identity is a socio-cultural 'construct' that is constantly redefined and reevaluated by diverse groups of people to serve their own interests.

Cultural Interaction (Rieger-Jandl, 2006)
Cultural change has traditionally occurred in some form or the other. But the significance of globalization is the unprecedented intensity and momentum of change that it entails. Cultural interaction is described as a mutual process. But in recent times cultural interaction has become a unilateral process owing to the domination global cultures. The immense speed and intensity of global cultural interaction differentiates globalization from similar historical influences like colonialism. Jandl (2006) argues that cultural interaction is characterized by one or more processes of acceptance or denial or both. One proposition of world culture suggests a process of 'consumption' and subsequent loss of identity. On the other hand, there is a tendency to construct new identities and social expressions.

Standardization: An International Architecture (King, 2004)
The nature of architectural production has become standardized in many ways. King (2004) argues that the internationalization of technology, trade and information, supported by revolutionary communication technologies such as the internet and computer aided design are some of the important factors. Architecture has been in many ways understood as an international or global profession. The issue of architectural standardization can be explained in terms of economics, unified architectural principles and construction systems. Increased mobility and telecommunications tend to alter the perception and experience of space, leading to a de-spatialized cognition.

Anthropological Dimensions in Architecture (Rieger-Jandl, 2006) (King, 2004)
Anthony king (2004) notes that an increasing number of architects all over world are engaged in the building of cultural environments that necessitate new guidelines for meeting cultural

challenges. Architects are beginning to realize that the issue of addressing culture in architecture requires an essentially interdisciplinary approach that draws from various other fields of knowledge. Architects are expected to be responsive to newly globalized cultures that are largely different from the existing types. Jandl (2006) contends that studies in the field of anthropology could become great resources for architects in addressing concerns about cultural change and anthropological methodology can provide helpful tools to architects in analyzing the needs and expectations of people.

MAKING NEW THEORY: SUSTAINABLE HYBRIDS

The analysis of vernacular and global building processes reveals that they interestingly share some common ground. Distinct notions emerge at various points in both global and vernacular building discourses and appear to be vital in connecting the two. The analysis contributes to developing a heuristic framework, which could then enable further analysis and action. In other words, this paper explores a relatively uncommon but yet seemingly important hypothesis of 'hybridization'. This hypothesis entails a dynamic cross-fertilization of vernacular and global building processes resulting in the creation of hybridized and sustainable processes. Scholars in both discourses have also identified future trends that could potentially be synthesized into a new conceptual framework or system of understanding for further research and action.

The Six Common Logics of Hybridization:

The six common logics that were derived during the logical argumentation process are discussed in following paragraphs. The assumption is that these vital conclusions are crucial in developing the hypothesis for a hybridized building culture. The six logics are considered as being the formative elements of the new system and are discussed in the following paragraphs.

Historical Context & Relevance

As with any new system, it is important to establish the historical context and relevance of the hypothesis in question. Scholars from both vernacular and global discourses expressed concerns about problematic historical approaches and the need to understand future trends of these discourses as well. It is important to situate the new system within the realm of the existing discourses in order to evaluate its historical appropriateness and applicability.

Interdisciplinary Approach:

Many scholars in both discourses express the need for an interdisciplinary approach and cultural awareness. An interdisciplinary approach is inevitable in the proposed new system as the premise of hybridization relies on this approach. The hybrid system will need to draw references from disparate sources across multiple disciplines such as anthropology, sociology, and so on in an attempt to build consensus for mediated action. A conceptual framework to study and analyze socio-cultural phenomena with common terms of reference will be needed.

Changes in the System of Architectural Education

Researchers from both discourses have argued for significant changes in the system of architectural education. Vernacular scholars have emphasized the necessity to document the vast numbers of everyday buildings in the study of architectural history. In addition, architecture schools have long emphasized the notion of studying buildings as purely esthetic objects. Hence scholars have reiterated the need to include historical analysis of building technology development in the curriculum.

Inspiration and Cultural Interaction

Inspiration and cultural interaction were addressed by scholars from the vernacular and global discourses, albeit in varying contexts. In the vernacular discourse, the dependability on local ideas was viewed as a constraint in promoting innovation. On the other hand, the intensity of cultural interaction and momentum of change brought by globalization were concerns raised by scholars in the global culture discourse. Cultural influences tend to impose new requirements. The new hybrid system proposes to develop an intermediary framework that could control the process of cultural interaction and facilitate a reflective cultural transformation process. In other words, mediated cultural interaction and/or transformation are important elements of hybridization.

Tradition and Identity

Rhetorically, tradition and identity are viewed upon as dominant constructs that restrict choices. Some scholars representing both discourses view the concept of tradition and identity as creative and continuous processes that are re-established and renegotiated from time to time. These processes when incorporated into a framework allow for choice and adaptation. The proposed hybridization aims to adopt this framework that views tradition and identity as creative processes, and in addition allows scope for innovation and change within the framework.

Cultural Adaptation and Appropriation

Cultural adaptation is one of the most essential factors in the proposed system of hybridization, especially in the context of globalization. As

discussed earlier, globalization has accelerated the process of cultural transformation and tends to prevent cultures from going through a process of cultural adaptation. Adoption of new ideas and elements from a foreign culture tends to undermine the process of cultural transformation. Similar to cultural interaction, the proposed hybrid system requires a framework to address the process of cultural appropriation. This framework could provide the necessary decision making tools and highlight the possibilities and/or limitations of cultural appropriation.

CONCLUSION

This paper concludes in what could be considered first steps towards a new direction i.e. hybridization. As opposed to providing conclusive evidences, these findings lead to more questions than answers. The six logics summarized above serve as a starting point for further research and action. Scholars, in both the vernacular and global discourses, have made suggestions to revitalize their respective discourses by redefining them in the contemporary context. What this paper is arguing is that there is potential for an active integration between the two discourses: vernacular and global building. Hybrids, in general, are beneficial combinations with greater value than natural products. In other words, the prospect of hybridization lies in its anticipated benefits. Hybridized building processes viewed in this way might not always result in beneficial outcomes due to the complex nature of building processes. A hybrid building framework is one in which the mutual sharing of diverse ideas, values and processes may result in the sustainable transformation of the built world.

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EVALUATING THE ENERGY PERFORMANCE OF EXTERNAL PERFORATED SOLAR SCREENS: EFFECT OF SCREEN ROTATION AND ASPECT RATIO

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ABSTRACT

External solar screens fixed in front of windows were traditionally used to conserve the cooling energy loads, achieve privacy, shading and daylighting control of buildings in hot climates. Modern perforated wooden solar screens with square or rectangular perforations, and fins perpendicular to screen surface similar to miniature egg-crate sun breakers were tested to investigate the effect of screens rotation on their energy performance.

This paper addresses the combined effect of changing screen rotation angle and aspect ratio on the annual cooling, heating and lighting energy loads. EnergyPlus simulation software was used in conducting series of experiments for a typical residential building.

Conclusions stated that rotating the slats of screen with squared perforation, had no significant effect on energy use. However, for screens with aspect ratios of vertical: horizontal=1:2, 1:4, 1:8 and 1:12, rotation of screens horizontal slats up and down affected the energy savings by up to 16%. Rotating the screen slats up to 30° downwards enhanced the screen energy performance

INTRODUCTION

Window solar gain considerably affects building energy consumption and peak cooling loads. Shading of windows reduces such loads and controls solar gain. The development of historical shading tools such as solar screens to more scientific and advanced forms can help in achieving the modern goals of sustainability and energy conservation, as well as high standard quality of life. Modern perforated wooden solar screens with square or rectangular perforations, and fins perpendicular to screen surface similar to miniature egg-crate sun breakers were tested to investigate the effect of screens rotation on their energy performance.

The paper builds on previous publications by the authors that addressed the energy performance of perforated wooden solar screens. In a previous publication, screen configurations in terms of depth and perforation ration that result in most significant savings were identified. These screens had a depth: perforation ratio of 1:1 with an 80% perforation percentage in the West and North orientations, and a 90% perforation percentage in the East and South orientations. The near optimum range extended from the 0.75 to 1.25 depth ratio, with perforation ratio between 80% and 90% in all orientations. In the West orientation, the highest energy saving was 30% (Sherif et al., 2012). In another related study, the influence of changing the perforation percentage of external perforated solar screens on the thermal performance of desert buildings was examined using the EnergyPlus simulation software. It was found that thermal loads dropped rapidly when screens with high perforation ratios were used. Screens with an 85% perforation rate provided significant energy savings. Reduction of perforation below this rate reduced thermal loads insignificantly. Reduction of the cooling energy was attributed to the substantial decrease in the transmitted solar energy and window heat gain energy (Sherif et al., 2010).

The rotation angle of other shading devices such as louvers ed in several publicaitions. External horizontal and vertical louvers were examined in several locations. TRNSYS software was used in performing the simulation runs, while EES was used in creating the model geometry. Results showed that louvers decreased energy consumption significantly and achieved thermal comfort especially in countries with high intensity solar radiation such as Cairo, Madrid and Lisbon. For countries with cold climatic conditions such as London, mechanical louvers can be rolled up in winter to decrease the heating loads and rolled down to decrease the cooling loads in summer (Palmero-Marrero and Oliveira, 2010).

External fixed horizontal shading devices of different slat lengths and tilts were tested using TRNSYS simulation in four cities in Italy. It was found that optimizing the louvers design decreased the cooling loads in summer achieving significant savings in the annual energy loads. Moreover, Louvers design varied in different locations and weather conditions (Datta, 2001).

The daylighting aspects of solar screens were analyzed in several publications. The effectiveness of solar screens axial rotation on daylighting performance was studied. It was found that for all orientations, as the rotation angle increased, the daylighting increased linearly. Screens rotation angle varied according to the change of orientation, season and time especially in the south and north orientations, where rotation angle from 0° to 30°

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influence was found to be significant in summer. However, for East orientation, the rotation angle influence was found to be significant in winter (Sabry, 2011).The effect of size of the solar screen gaps on reflected sunlight through screens was studied. Daylighting was found to be lower in rounded screens having larger cell diameters. This was attributed to the ratio of openings to solid parts of the screen panels. Screen reflectance was also investigated. It was found that light colored screens increase the average daylighting factor percentage by 17% compared to the dark coloured screens (Aljofi, 2005). Moreover, the average illuminance levels resulting from use of solar screens on windows of a designed living room were measured for different window orientations over a range of day times in different seasons. The resultant quantity of room daylighting was investigated and recommendations for minimum screen perforation were presented. Conclusions were drawn stating the adequacy of these solar screens in terms of luminance values in different orientations, seasons and times (Sherif et al., 2010). Solar screen perforation openings aspect ratio was studied, where the illuminance levels in the clear sky condition location of El Sadat City (30.2˚N - 30.2˚E) was demonstrated. It was found that for South and North orientations, illuminance levels resulting from changing the solar screen opening proportions till 1:6 increased significantly compared to the base case. However, from 1:6 to 1:32 proportions the daylighting performance was slightly enhanced. For East orientation, an increasing trend in daylighting performance was observed by increasing the proportions till 1:12 ratio. Similar results were achieved in the West orientation. Therefore, for all orientations, 1:6 and 1:5 proportions can provide a satisfactory balance between energy efficiency and daylighting (Sherif et al., 2011).

Solar screens of circular openings design and analysis were examined algorithmically by using a generic optimization procedure to control daylighting levels. Altering the openings arrangement of a couple of solar screens generated desirable light and shadow patterns (Lockyear, 2010).

SIMULATION SETUP

Experimentation was conducted using the EnergyPlus simulation software, where the Design Builder application was used as an interface and modeling tool. The architectural parameters were selected according to the principal features of a typical dwelling lounge. Simulations were carried out using the subtropical environment of Kharga Oasis, Egypt, located in the African Sahara. Specific “base case” input parameters were assumed so as to be opening-tuned in order to focus on the thermal effect of using the tested screens. These were detailed in table (1).

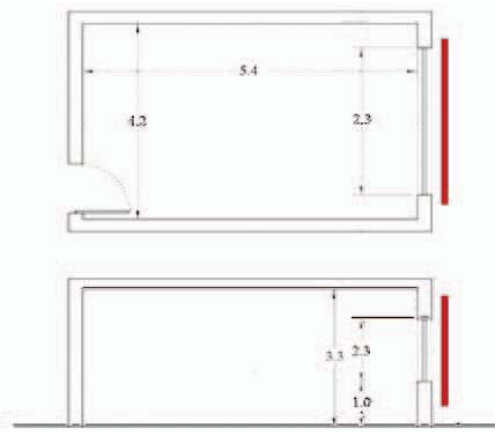


Figure 1 Design space plan and cross section.

The base case is a dwelling lounge isolated from the external environmental thermal changes by assuming that all surfaces, other than the external tested wall, were adiabatic. Thus, three walls, floor and roof were assumed adiabatic. The fourth wall was defined as a 350 mm thick double brick insulated cavity wall with a U- value of 0.475 W/m² –k that carried a window at its center. A split-unit type air-conditioning system was assumed. The heating and cooling set points were 23 ˚C, while the set backs were 25°C. The heating supply air temperature was 35 ˚C. The cooling supply air temperature was 12 ˚C. The minimum fresh air requirements were set to 10.0 l/s-person. Artificial lighting was set to be dynamically controlled by sensors according to daylighting adequacy. A daylighting control was set up with an illuminance set point of 300 lux at the centre of the dwelling lounge. The internal occupants’ load was accounted for, while the energy consumption of appliances was not considered (Figure 1).

Table 1 Dimensions and parameters of the tested dwelling lounge, window and solar screen.

DWELLING LOUNGE SPACE PARAMETERS	
Floor level	Zero level
Wall Thickness	0.35 m
WINDOW PARAMETERS	
Dimensions	2.30 m * 1.20 m
Sill Height	1.0 m
WWR	20%
Material	generic double clear glazed separated by 13mm air gap
Light Transmission	0.75
SOLAR SCREEN PARAMETERS	
Dimensions	2.70 m * 1.80 m
Perforation	80%
Material	Dark brown matt painted Oakwood
Position	50mm from the window
	0.7m height from ground
Shape	Orthogonal grid of rectangular section bars
Perforation Rate	80%
Slats Rotation Angles	Ranging from 0˚ to 60˚

SOLAR SCREEN PARAMETERS

Rotation of the screen slats affects the energy use. This effect varies when changing screen aspect ratios. Accordingly, the combined effect of changing the screen aspect ratio and rotation of screens horizontal slats up and down with varying degrees was examined for each orientation. The search for optimum louver angles ranged from θ = 0˚ to 60˚ for screens with aspect ratios of vertical: horizontal=1:1, 1:2, 1:4, 1:8 and 1:12. The results were compared with the base case of zero angle rotation. Figure 2 illustrates the investigated rotation angles of horizontal screen slats upwards and downwards.

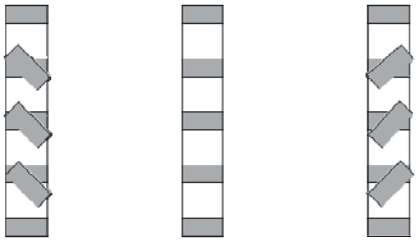


Figure 2 Screen horizontal slats tilt angles.

Moreover, the effect of rotating the screen itself, while changing the screen perforation aspect ratio was examined for the southern orientation. The search for optimum screen rotation angle ranged from θ = 0˚ to 90˚ clockwise and anticlockwise for screens with aspect ratios of vertical: horizontal= 1:1, 1:2 and 1:4 (Figure 3). The results were analyzed and discussed in comparison with the base case of zero angle rotation.

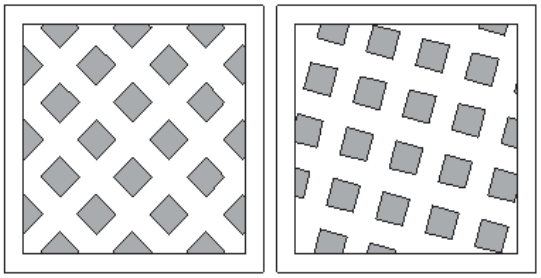


Figure 3 Screen rotation angle.

RESULTS AND DISCUSSION

Solar screen with an aspect ratio of V: H=1:1

For external solar screens with orthogonal grid of square section bars and high perforation ratio of 80 and optimal aspect ratio of V: H=1:1, rotating the screen slats didn't affect the screen energy performance, where a wide range of screen tilt angles from 15° upwards to 30° downwards had no effect on energy savings. However, rotating the slats other than that can deteriorate the energy losses up to 18% (Tables 2 and 3).

Table 2 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:1.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	-1%	-1%	-1%	-17%	-18%
West	-1%	0%	0%	-17%	-17%
East	-1%	0%	0%	-16%	-17%
North	-1%	-1%	-2%	-18%	-18%

Table 3 Energy savings percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:1.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-1%	-1%	-4%	-9%	-11%
West	-1%	-3%	-6%	-9%	-10%
East	-1%	-2%	-6%	-8%	-9%
North	-1%	0%	-3%	-3%	-4%

The total energy loads increased with the increase of screen slats roation angle downwards. This could be attributed to the fact that as the screen rotation angle increased, the daylighting decreased resulting in a more use of artificial lighting. On the other hand, rotaion of screen slats upwards up to 30° enhanced the daylighting leading to a slight decrease in the lighting electricity and the total energy loads. However, rotating the slats more than 30° upwards lead to a considerable decrease in daylighting and accordingly an increase in the lighting and total energy loads (Figures 4, 5 and 6).

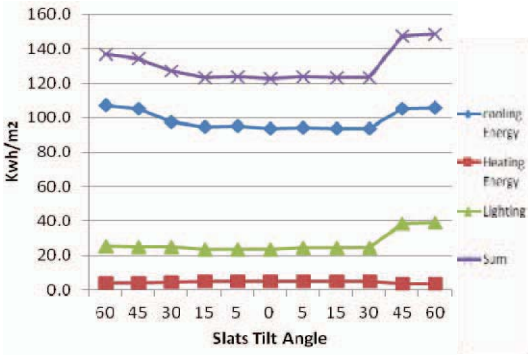


Figure 4 Energy consumption for solar screens with aspect ratio of V: H=1:1 for slats tilt angles from 0° to 60° upwards and downwards- South.

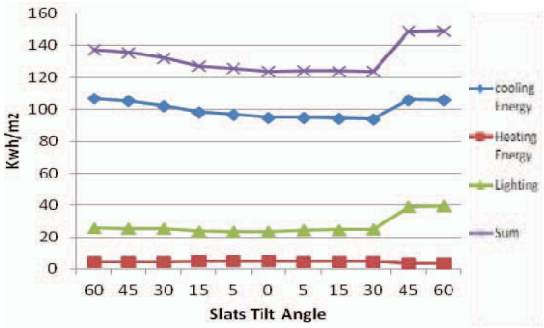


Figure 5 Energy consumption for solar screens with aspect ratio of V: H=1:1 for slats tilt angles from 0° to 60° upwards and downwards – West.

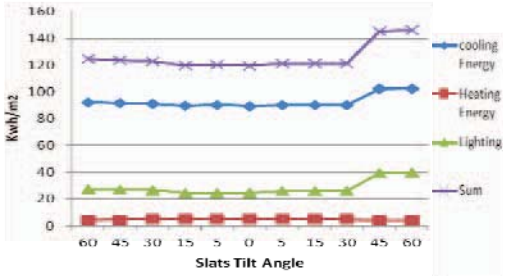


Figure 6 Energy consumption for solar screens with aspect ratio of V: H=1:1 for slats tilt angles from 0° to 60° upwards and downwards – North.

Solar screen with an aspect ratio of V: H=1:2

Unlike screen with previous aspect ratio, rotating the screen slats upwards for the solar screen having an aspect ratio of V: H=1: 2 enhanced the screen energy performance significantly. The total energy savings in comparison with the base case of screen with zero rotation reached 13, 14 and 16% when the screen slats were rotated upwards by 5° and 15° for the West, South and North orientations respectively. This increase in energy savings could be due to the significant improvement in daylighting that resulted in the decrease in lighting electricity and the total energy loads. Increasing the tilt angle to 30° slightly decreased these savings to 10%. However, Increasing the tilt angle upwards to 45° and 60° gave a drastic loss in energy by 7% and 9% respectively due to lack of daylighting that led to the increase in lighting electricity and consequently the cooling loads. This is attributed to the increase of the lighting loads that consequently resulted in extra heat gain dissipated by electrical lamps (Figures 7, 8 and 9).

On the other hand, rotating the slats tilt angle downwards gave a negative impact up to 9% losses in energy compared to the base case due to the increase in the lighting and cooling loads. Near optimum range extended from 5° to 30° upwards. However, rotating the slats downwards more than 30° upwards gave a negative impact (Tables 4 and 5).

Table 4 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:2.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	-3%	-4%	-6%	-7%	-8%
West	-3%	-4%	-5%	-6%	-7%
East	-3%	-4%	-5%	-7%	-7%
North	-2%	-3%	-4%	-6%	-6%

Table 5 Energy savings percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:2.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	13%	13%	10%	-7%	-9%
West	13%	13%	8%	-6%	-8%
East	14%	14%	9%	-7%	-9%
North	14%	16%	12%	-5%	-6%

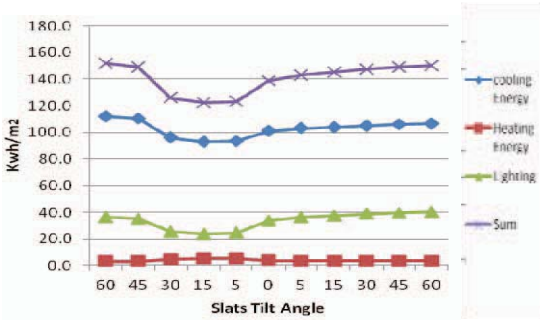


Figure 7 Energy consumption for solar screens with aspect ratio of V: H=1:2 for slats tilt angles from 0° to 60° upwards and downwards –South.

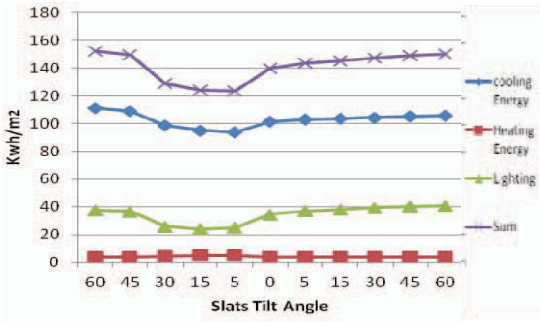


Figure 8 Energy consumption for solar screens with aspect ratio of V: H=1:2 for slats tilt angles from 0° to 60° upwards and downwards – West.

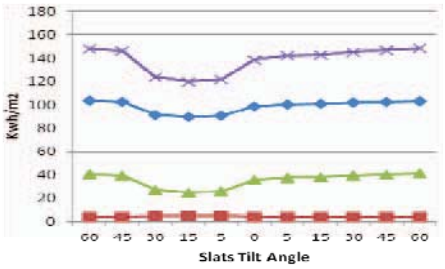


Figure 9 Energy consumption for solar screens with aspect ratio of V: H=1:2 for slats tilt angles from 0° to 60° upwards and downwards – North.

Solar screen with an aspect ratio of V: H=1:12

Tables 6 and 7 illustrate the annual energy savings for alternative solar screens. In the South, when the screen slats were rotated downwards by 15° and 30°, the energy savings in comparison with the base case reached only 1%. Increasing the tilt angle to 45° and 60° gave a drastic loss in energy by 11% and 13% respectively due to lack of daylighting that lead to the increase in lighting electricity and consequently the cooling loads (Figure 6). On the other hand, rotating the slats upwards gave a negative impact due to the significant increase in the cooling loads. When the screen slats are rotated upwards, energy savings were reduced by 2 to 16%.

Table 6 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:12.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	0%	1%	1%	-11%	-13%
West	1%	3%	5%	-7%	-8%
East	0%	2%	3%	-9%	-10%
North	-1%	-1%	0%	-14%	-16%

Table 7 Energy saving percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:12.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-2%	-4%	-12%	-17%	-16%
West	-2%	-6%	-11%	-13%	-10%
East	-2%	-5%	-10%	-12%	-10%
North	-1%	-1%	-4%	-4%	-4%

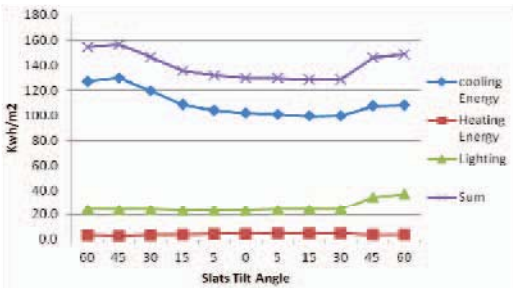


Figure 10 Energy consumption for solar screens with aspect ratio of V: H=1:12 for slats tilt angles from 0° to 60° upwards and downwards – South.

In the West orientation, rotating the screen horizontal slats downwards led to significant energy savings up to 5% with 30° rotation. Increasing the tilt angle to 60° gave a drastic loss in energy by 8% due to lack of daylighting (Figure 11). On the other hand, rotating the slats upwards gave a negative impact due to the significant increase in the cooling loads. When the screen slats are rotated upwards, energy savings are reduced by 2 to 13%. East facades gave a similar trend with maximum savings reaching 3%. The best performance was achieved with slats rotated 30° downwards.

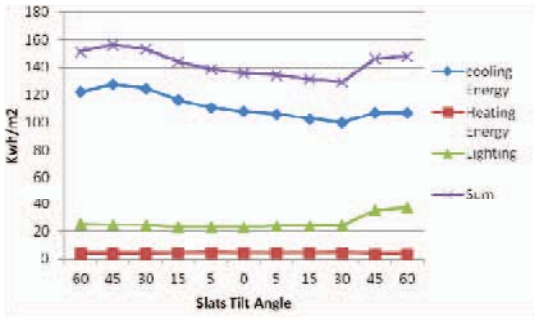


Figure 11 Energy consumption for solar screens with aspect ratio of V: H=1:12 for slats tilt angles from 0° to 60° upwards and downwards – West.

In the North, rotating the screen slats either upwards or downwards led to a negative effect compared to the base case. Rotating the slats upwards created losses (up to 4%) which is less destructive than downward rotation (up to 16%) (Figure 12). Accordingly, screen slats shouldn't be rotated in the northern façade when using screens with perforation aspect ratio of V: H =1:12.

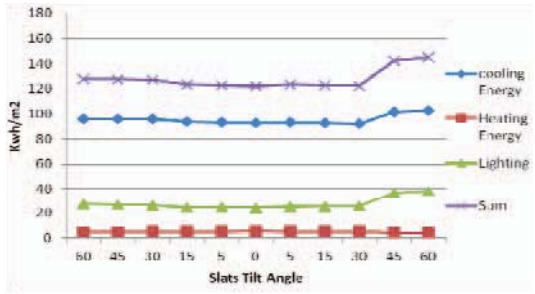


Figure 12 Energy consumption for solar screens with aspect ratio of V: H=1:12 for slats tilt angles from 0° to 60° upwards and downwards – North.

Solar screens with aspect ratios of V: H=1:8 and 1:4

A similar behavior was noticed by changing the screen aspect ratio from V: H of 1:12 to V: H of 1:8 or 1:4 with lower energy saving percentages, especially in the South orientation (Tables 8, 9, 10 and 11).

Table 8 Energy saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:8.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	0%	0%	0%	-12%	-14%
West	1%	3%	5%	-8%	-9%
East	0%	2%	3%	-9%	-11%
North	-1%	-1%	0%	-14%	-16%

Table 9 Energy saving percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:8.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-1%	-4%	-10%	-17%	-15%
West	-2%	-5%	-11%	-12%	-10%
East	-2%	-5%	-10%	-11%	-10%
North	0%	-1%	-4%	-4%	-4%

Table 10 Energy Saving percentages due to changing screen slats tilt angles downwards angles for solar screens with an aspect ratio of V: H=1:4.

DIRECTION	DOWN				
Tilt Angle	5	15	30	45	60
South	-1%	0%	0%	-13%	-15%
West	0%	2%	3%	-10%	-12%
East	0%	2%	3%	-11%	-13%
North	-1%	-1%	-1%	-15%	-17%

Table 11 Energy saving percentages due to changing screen slats tilt angles upwards angles for solar screens with an aspect ratio of V: H=1:4.

DIRECTION	UP				
Tilt Angle	5	15	30	45	60
South	-1%	-2%	-8%	-15%	-14%
West	-2%	-5%	-10%	-12%	-11%
East	-2%	-5%	-11%	-13%	-11%
North	-1%	-1%	-4%	-4%	-12%

Effect of rotating the screen parallel to the window

The effect of rotating the whole screen in the southern orientation for screens with aspect ratios of vertical: horizontal= 1:1, 1:2 and 1:4 on the building energy performance was investigated. The rotation angle ranged from θ = 0˚ to 90˚ clockwise and anticlockwise to identify the optimum rotation of each aspect ratio (Figure 13).

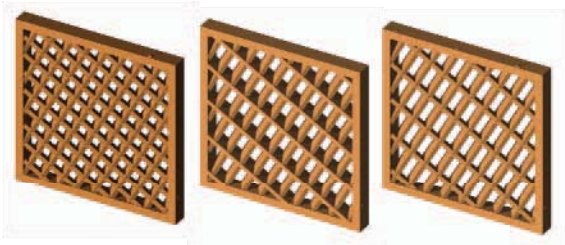


Figure 13 Screen rotation angle with aspect ratios of V: H=1:1, V: H=1:2 and V: H=1:4 respectively.

Table 12 Energy saving percentages due to changing screen rotation angle clockwise for a solar screen with an aspect ratio of V: H=1:1.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1.2	1.4	1.4	2.8	2.1	0

Table 13 Energy saving percentages due to changing screen rotation angle anticlockwise for a solar screen with an aspect ratio of V: H=1:1.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1.5	1.6	1.1	3	2.4	0

Table 14 Energy saving percentages due to changing screen rotation angle clockwise for a solar screen with an aspect ratio of V: H=1:2.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	0.7	1.5	1.6	1.5	2.4	3.1

Table 15 Energy saving percentages due to changing screen rotation angle anticlockwise for a solar screen with an aspect ratio of V: H=1:2.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1	1.8	1.8	1.8	2.7	3.1

Table 16 Energy saving percentages due to changing screen rotation angle clockwise for a solar screen with an aspect ratio of V: H=1:4.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	1	1.5	1.5	1.7	1.6	3.3

Table 17 Energy saving percentages due to changing screen rotation angle anticlockwise for a solar screen with an aspect ratio of V: H=1:4.

ROTATION ANGLE	5	15	30	45	60	90
ENERGY LOSSES %	0.9	1.7	2.3	2.9	3.1	3.3

For the screen with an aspect ratio of squared perforations and V: H=1:1, rotating the screen to 45° led to increasing the losses in energy savings up to 2.8% (Tables 12 and 13). For the screens with aspect ratios of V: H=1:2 and V: H=1:4, rotating the screen clockwise led to increasing the losses in energy up to 3.3% at 90° rotation angle. In other words, when the horizontal openings rotate 90° till they become vertical. This complies with previous results found in the literature that demonstrated the significance of using horizontal perforations in reducing the energy loads for the South orientation (Tables 14, 15, 16 and 17).

CONCLUSION

External solar screens are typically used to reduce the energy loads of buildings. The revival of modern angled types of perforated wooden solar screens can lead to significant energy savings. This paper investigated rotating the solar screen either itself or its slats to search for optimum louver angles ranging from 0˚ to 60˚ up and downwards in different orientations.

For the screen with squared perforation and optimal depth ratio of 1, rotating the screen slats had an insignificant effect on screen energy performance. However, for screens with aspect ratios of vertical: horizontal=1:2, 1:4, 1:8 and 1:12, the combined effect of changing the screen aspect ratio and rotation of screens horizontal slats up and down affected the energy savings by up to 16%. Rotating the screen slats up to 30° downwards enhanced the screen energy performance. However, exceeding 30° gave a negative effect due to lack of daylighting that led to the increase in the lighting loads. On the other hand, rotating the slats upwards deteriorated the energy performance significantly.

Furthermore, the effect of rotating the whole screen in the same plane parallel to the window, while changing the screen perforation aspect ratio was investigated. Rotating the screen decreased the energy savings up to 3% at 90° rotation angle (vertical perforation). Accordingly, screens of square and horizontal perforations perform better than screens with vertical perforations.

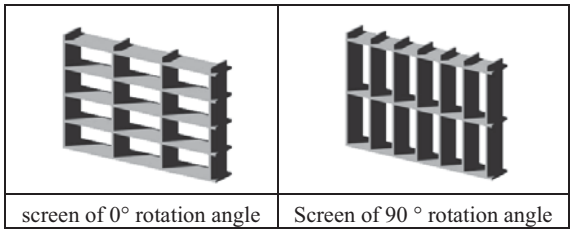


Figure 13 Recommended screen with 0° rotation angle vs. Screen of 90 ° rotation angle *that should be avoided in the South.*

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DEVELOPING AND IMPLEMENTING BUILDING ENERGY EFFICIENCY IN EAST AFRICA & GREEN BUILDINGS

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ABSTRACT

Showcasing planning and implementation elements in improving and adjusting the building codes to meet current and future planning for buildings in East Africa namely Tanzania, Rwanda, Burundi, Uganda and Kenya. The work with the support of UN Habitat , is associated in getting key stakeholders involvement on legislative/voluntary levels and addressing various issues from cost and integration issues faced.

Too often a pure criterion by criterion approach leads to a collection of costly independent green features or a matured design aspect which fails to integrate with sustainability. One key project will be presented on how these factors overcome through team integration , sourcing and support from key stakeholders

Sustainable affordable housing , Project Kibada , by National Housing Corporation along will be presented. The project is registered and going for certification under the BCA Green Mark scheme,

Coverage on challenges, cultures barriers, cost, stakeholder engagement, will be discussed.

INTRODUCTION

Implementing green buildings, energy efficient houses or development in East Africa is a challenging task. No doubt the benefits such as energy / water savings etc. , are clear however getting approval from stakeholders remains a daunting task.

Constant shortage of energy; results than driven by the supplement of generator set should all indicate the importance of energy conservation. Yet again, the section on energy conservation has to be addressed by and large on ministerial level and to be adopted across all sectors with focus on energy intensive buildings and simply design to achieve sustainable building operations and function.

Under a 5 years program managed by UN Habitat, named EEBEA , Energy Efficiency Building in East Africa in collaboration with 5 countries namely Tanzania , Kenya, Uganda, Rwanda and Burundi, and UNEP enables the implementation of the said purpose.

The objectives of the programme is to,

1. To mainstream energy efficient measures into Housing Policies, Building Codes and Building Practices in East Africa
2. To achieve considerable reduction of GHG emission as a result of improved energy efficiency.

The target are to achieved within 5 years

1. 600,000 units , governmental units of mass housing
2. 100 buildings build/ retrofitted under energy efficiency standards
3. Energy reduction in buildings by 30-50%
4. Energy savings in existing building by up to 30%
5. Increased number of people with assess to modern energy

Estimated reduction in 20 years of

1. Direct CO2 reduction : 3,629,996 ton
2. Indirect CO2 savings : 3,937,500 ton

Results of which can be observed from the handful of projects that has materialise over the short period of time

WORKING PLAN

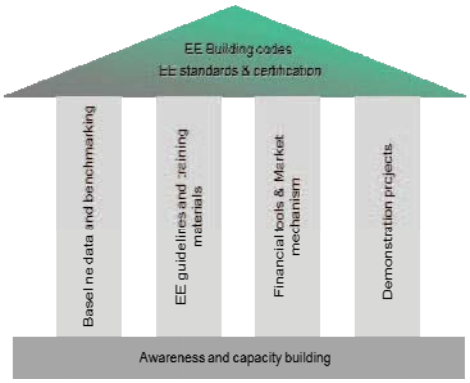
The following plan has been put in place for a period of 5 years. The plan consist of

1. Baseline Data, Benchmarking on Energy Efficiency (EE) in the Building Sector and Energy Audits.
2. Adoption of Energy/Resource Efficient Building Codes in the region: EE standards & certification.
3. Awareness Raising; Capacity Building, EE guidelines and training tools.
4. Appropriate Financial Framework for the Promotion of EE Measures in Buildings.

Integration of EE measures in all government housing projects, donor funded housing projects and encourage such practices in the private sector as illustrated in Figure 1

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Figure 1
Working Plan Model



Baseline Data and Benchmarking

Universities within each country has been tasked to conduct energy audits and collect data in buildings and household to pool a set of figures than can be used to set up a baseline according to topologies of building and various climate zone

In countries where purchase energy is common and generator is used to supplement energy shortage it is a difficult exercise to monitor energy consumption in a sparse area/households of whom do not monitor own consumption.

However efforts are on-going to set up a baseline and in identifying savings potential.

Capacity Building, Training

Sensitizing stakeholder on green building concepts and passive building. Creations of workshops, training manuals and actual project exercise is the way forward to showcase actual implementation of ideas and empowering the capability to believe that the changes can be implemented with proper planning and no less.

Along the way, the 1st Handbook of Sustainable Architecture for East Africa is being developed .

The handbook will provide guidance on but not limited to climatic, design issues, green building certification and various comparison of energy efficiency codes for implementation

Financing Instruments

To enable / encourage usage of energy efficiency in various financing tools that could facilitate the adoption and establishment of a green mortgage system.

Governmental bodies are encourage to create fiscal and administrative incentives ; subsidies programme and to allocate national budget for promoting energy efficiency in buildings .

ENERGY EFFICIENCTY CODES

Climate

Climate research was conducted to enable the study of various climatic conditions in the various countries

Groupings of climates is sum up in Figure 2 below

Figure 2
Classification of climates

Weather	Temperature (deg Celsius)	Humidity (%)
Hot Humid & semi humid	25 -32	75 - 80
Hot Arid	23 -36	40
Upland	14 -27	60 - 65

Solar radiation for all groupings remains significant and varies between 4.5 – 7 kwh/m2.
Generally the use of passive solar heating and renewable energy is greatly encouraged

Overall climates is shown in Figure 3

The study summarizes a general knowledge that the following should be adapted for building design similar to tropical climates in Asia

- Passive Cooling though stack effect ventilation
- Thermal insulation properties of building envelope and roof
- Attention to building solar/wind orientation
- Natural lighting adoption
- Energy Efficiency Code and Renewable energy

However, in some areas concern on humidity may lead to mould and care need to address in design.

Similarly the dependency on artificial cooling will be highly sought after in commercial spaces and some residential units.

As such the energy efficiency of both artificial lighting and cooling together with proper façade design need to be addressed to maximize the potential of energy efficiency.

Through the implementation of projects the following was discovered

Artificial Cooling

Commercial projects are more comfortable with the use of condensing units or air chillers in comparable to water cool chiller which are of higher efficiency.

Problems sighted in adoption cooling equipment's are ,

- Up keep of chilled water units
- Supplier source and reliability
- Cost
- Technical know how

Lightings

Adoption and awareness of energy savings lighting are vast and significant projects have implemented good usage of energy efficient lights such as high frequency ballast and LED.

Energy

In general the main fault lies within the overdesign of both artificial cooling and lighting that leads to extensive usage of energy over period of time with higher investment cost.

Energy Efficiency of both adopted through comparison of ASHRAE and the Singapore Standard SS530 code was tabled for discussion and future adoption.

Building Envelope

Most if not all the buildings are highly glazed. This creates a challenge in increasing the energy efficiency in building and retrofitting existing building.

Following are methods of computing heat transmission within a building tabled for discussion and adoption

- Energy modelling, modelled as a whole building to determine cooling requirements
- Different prescriptive methods using the computation of the overall building envelope based on thermal resistance, window wall ratio and set values to achieve target depending on climatic zones

Whichever method adopted need to be palatable to the current working climate and stakeholders.

PROJECT IMPLEMENTATION

During earlier implementation of the project, a workshop was conducted in Uganda where participants bring along projects to enable the implantation of green building and energy efficiency concepts. Project Kibada was brought to desk for a study along with other projects.

The project was brought to discussion on ways to be built sustaninably and energy efficient.

Project Summary

A total 190 affordable houses of 2 and 3 bedroom cluster with facilities such as school and parks within the compound. The project is in Kigambuni area called Kibada and belongs to National Housing Corporation of Republic of Tanzania. See attached Figure 4

Challenges

The project was in the early construction stage. As such there were already houses built and changes to design , pricing is a challenge as budget has been set . To overcome this, modification was made where its useful to habitable spaces and which increase efficiency in construction whilst minimizing environmental impact.

Design Adoption

Design of the 2 bedrooms have limited ventilation and day lighting and heat trap areas within the houses Changes : Cross ventilation , removal of heat trap areas through openings and manual open able opening above all doors and windows and enlargement of opening in wet areas such as toilets are kitchen.

Energy Efficiency

Windows are made of UPV as good source of heat barrier and glass are tinted though not of energy savings specification, the choice of colour being the only factor to mitigate heat due to budgetary constraints

Fan Points , no artificial cooling and lighting levels are chosen mainly energy savings fluorescent tubes .

Selection of energy efficient refrigerator based on Singapore NEA 4 tick of energy conservation to be used in the houses.

Water Efficiency

Low reduction of sanitary fittings is brought in to reduce water consumption for each household.

A community underwater rainwater harvesting was introduced for the community to use as non portable waste source for cleaning and to reduce the dependency on precious portable water

Materials

Initial stage of the house walls was made of sand and cement. The heat transmittance was poor and did not manage to passively cool the house. The difference in thermal value as per Appendix 5

Figure 5
Wall Value comparison

Description	U value (w/m2K)
150mm concrete wall	3.013
230mm Hydro foam wall	1.32

Walls are made of interlocking, soil blocks, compressed together using a machine. The walls are made of soil within the site hence this reduces the transportation period and used material within location which in return enhances the construction speed.

The walls are dry staked with limited uses of mortar This minimizes environmental impact and thermal transmittance of soil passively cools the building . See Figure 6.

Other local materials such as wood for doors , Tanga stone and gravels are all source within the country.

Local paint with low voc content was sourced and used to promote good indoor air .

Social and Economic

Houses are locally built with local labours. Local manpower are used to built the house and train on many trades , workmanship ; plumbing, construction of wall etc.

This generates a ripple workforce effect which provide employment not only to the direct labour force but also to the surrounding community who supports the workforce.

Construction Wastage

The pure nature of construction was design to minimize wastages, as such all materials are pre-fabricated and installed on site. Metal roofing are fabricated off site and installed as it is.

Compacted soil walls wastages are crush and fed in to the wall compactor machine and re-use to form new walls.

Excavated soils are either used for the walls or salvaged for public greenery, hence this closed loop process of material usage maximize fully every bit of surrounding material used.

Green Certification

The project has been assessed for the First affordable public housing in Tanzania using the BCA Green Mark Landed Houses Criteria.

The process was not on a certification criterion on criterion approach but rather on a consumer end benefit driven approach to create affordable and thermally comfortable sustainable housing for the mass public in line with the UN Habitat objective .

The project has taken into account beyond what is stipulated within certification criteria and uses green concept values , socially and economically

Acknowledgement

This document consist partially from a series of documents written or distributed from the EEBA workshops and research .

Figure 3
Climate Zone of EAC

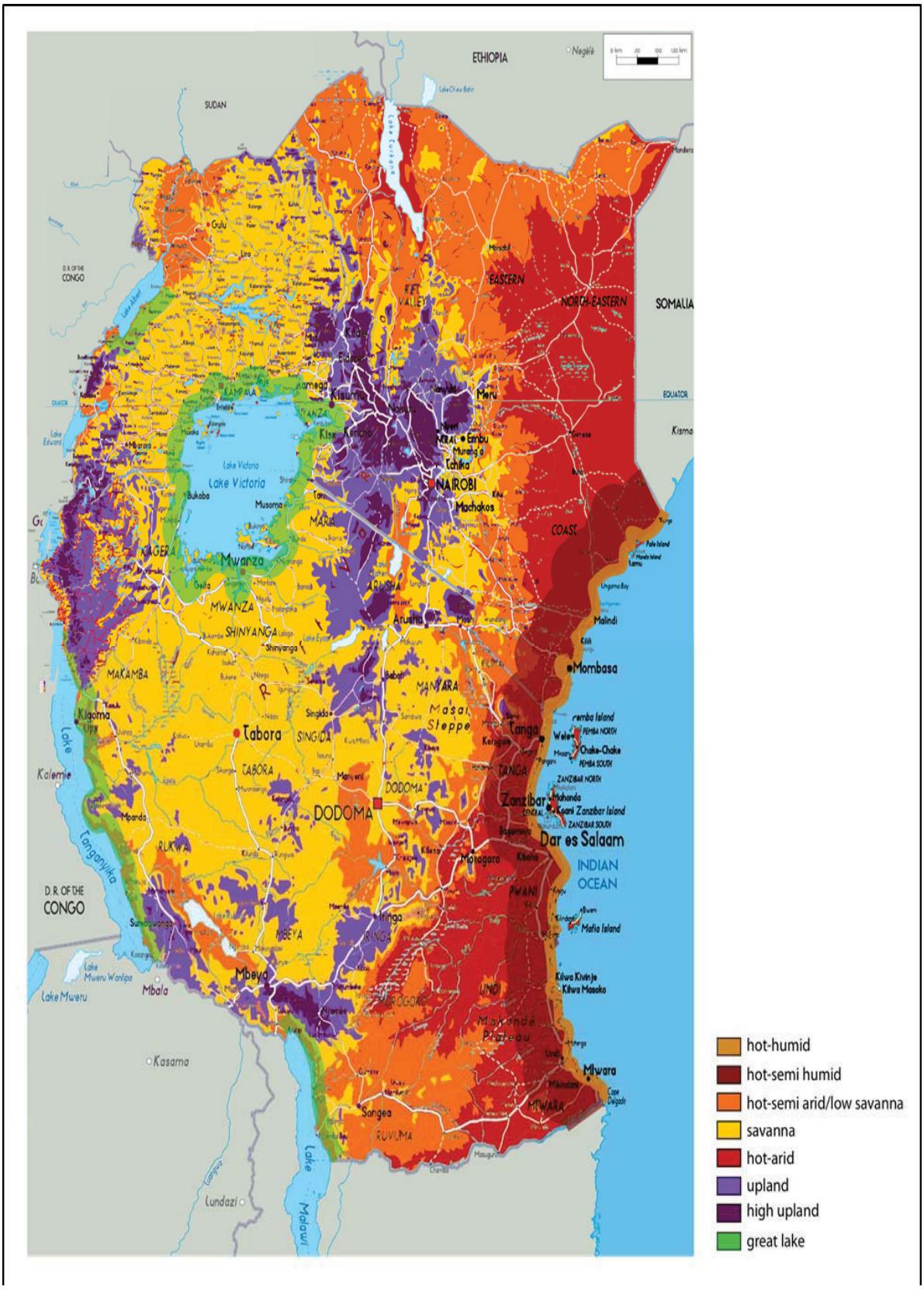


Figure 4
Housing Master Plan



Figure 5
Before : Cement, Sand Concrete walls





Figure 5
After : Soil Compacted Walls





A SUSTAINABLE URBAN BUILT ENVIRONMENT USING RECYCLED AGGREGATE CONCRETE

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ABSTRACT

In this paper, the properties of recycled concrete aggregate (RCA) and green-concrete were investigated. The properties of RCA and virgin aggregate were compared. It was found that generally the properties of RCA were of lower quality than virgin aggregate. The properties of harden concrete which contains RCA have also been investigated. Six concrete mixes were designed with different percentage of RCA; the proportions of the mixture were kept constant except admixtures. Cube and beam specimens were cast and tested at different age of the concrete. The compressive strength decreased by 10 to 12% when 100% RCA is used and compared to fresh concrete. Petrography analyses shown that all concrete were acceptable. Six beam specimens were subjected to 4-point bending and all specimens had similar ultimate load. Specimens with high percentage of RCA were more likely to crack and were not as stiff as specimens with a lower content of RCA. It was concluded that up to 50% of RCA can be reused into fresh concrete.

Keywords: Green-concrete, Sustainability, RCA, Structures

INTRODUCTION

Also, the concepts of sustainability and sustainable development was introduced at the 1992 Earth Summit in Rio de Janeiro, Brazil, and it is now a guiding principle for governments and most industries worldwide.

Nowadays concerns for the future generations and their right to a clean environment are increasing. Therefore, sustainability has become more and more important and it is a matter of interest for politics and industries such as food, energy, water, materials as well as the built environment. For example, two major events, i.e. the "SB13 Singapore, Realising Sustainability in the Tropics conference" and the "Urban Sustainability R&D congress 2013" will take place in Singapore between June and September 2013.

The amount of waste from construction and demolition has increased considerably over the last twenty years worldwide and in Singapore in particular with en-bloc sales for example. In fact, governments are now promoting various measures that aim at reducing the use of primary aggregate and increasing reuse and recycling of materials reclaim from demolition, where this is technically, economically, or environmentally acceptable. It has been shown that the extraction of natural aggregate contributes to the depletion of non-renewable natural resources and it affects the surrounding fauna and flora. To reduce human footprint and decrease the depletion of natural resources it is important to reduce the reliance on virgin aggregate from the construction sector and therefore it is necessary to recycle and reuse aggregate reclaimed from demolition work.

Many studies that show the potential applications of recycled concrete aggregate (RCA) are increasing worldwide. Materials from demolition were initially recycled for non-structural applications such as road construction or pavement for example. Approximately one decade ago the investigation of the potential reuse of RCA for structural applications became increasingly popular with studies from dos Santos et al. (2004) and Gonzalez et al. (2004) for example. More recently, a study from Etxeberria et al. (2006) has shown that up to 25% of the coarse aggregate can be replaced by RCA into fresh concrete without compromising the mechanical properties, such as compressive strength, of the harden concrete. Etxeberria in his study achieved a constant compressive strength of the concrete by adjusting the water/cement ratio.

The quality of aggregate has been investigated by Sagoe-Crentsil et al. (2000) and Kwan et al. (2010) and it has been shown that the reclaim process affects the shape and texture of the aggregate and therefore its quality and properties (mechanical and chemical for example.) The quality of the aggregate in its turn will also influence the properties of the fresh and dried concrete as well as the final product (structural or non-structural).

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Sanchez de Ruan et al. (2009) shown that the old mortar attached to reclaimed aggregate increases the sulphate content of the reclaimed raw aggregate. RCA also has high water absorption (due to the old mortar attached to RCA) and therefore the workability of concrete is affected as well as the properties of the dried concrete (Koulouris et al. 2004). Other studies, such as the one by Shi et al. (2008) for example, have shown that the percentage of RCA used in the mixture affects the modulus of elasticity of the concrete.

Currently concrete has become popular to eliminate waste from other industries. It has already been shown that copper slag (Al-Jabri 2009), fly ashes (Shi et al. 2008), tires (Sgobba 2010 and Wong 2009) and coconut fibres (Nadzri at al. 2012) for example can be used or recycled into fresh concrete. Currently France is looking at the possibility to use concrete to store permanently nuclear waste.

As Singapore does not have any natural resources for construction (sand, aggregate and cement for example), recycling of concrete waste is major importance due to environmental protection acts in countries that used to export natural aggregates to Singapore, for some time, local construction industry faces a shortage of aggregates batching plants. Thus, recycling aggregates presents one important means to meet the demands of aggregates for the local industry for non-structural and structural applications

This project aimed to investigate the properties of the aggregates, harden concrete as well as the behaviour up to failure of structural beam elements subjected to 4-point loading.

CONCRETE DESIGN

The concrete mixtures were design to achieve a concrete grade 40. The proportions of cement water, coarse and fine aggregate were kept constant and are shown in table 1. Six mixes were designed using 0, 20, 40, 60, 80 and 100% of RCA as coarse aggregate. The slump was controlled and kept constant by adjusting the amount of admixtures. Trial mixes were conducted at Pan United production plant to determine the optimum quantity of admixtures to ensure that the slump was within the targeted value of 100mm±25.

At the production plant, $2m^3$ of concrete were made for each mix to cast cube and beam specimens. An initial batch was made and discarded. Its aim was to run in the batching plant to ensure that the operating conditions inside the mixer were appropriate such as humidity for example. Then the first mix was made using virgin aggregate only (0% RCA), the following mixes included an increasing percentage of RCA, 20, 40% and so on until the final batch with 100% of RCA as coarse aggregate.

Table 1
Concrete Mixture

	Material type	Quantity per m^3 (kg)
Cement	OPC	400
Coarse aggregate	20mm	950
Fine aggregate	Sand	785
Water	PUB	185

PROPERTIES OF THE AGGREGATE

The particle size distribution was measured for the both types of aggregate (virgin and recycled) as shown in figure 1. As can be seem the size distribution of the virgin aggregate was within the upper and lower limit of the Singapore Standard, SS73:1974. On the other hand the size distribution of the RCA did not comply as the percentage of aggregate smaller than 10 mm and 20 mm are slightly too low when compared to the lower limit from the Standard.

Nevertheless, it was shown that when mixed the two types of aggregates up to 40% of Virgin aggregate and 60% of RCA, then the resulting aggregate was within the limit of SS73:1974. Only when more than 60% of RCA was used the particle size distribution did not meet the criteria set by SS73:1974. For this research project, it was decided to proceed with the batch of RCA received as it reflects the quality of recycled aggregate currently available in Singapore.

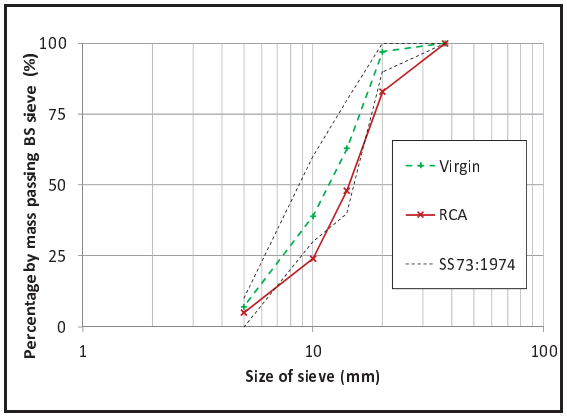


Figure 1 Particle size distribution of coarse aggregates (virgin and RCA)

Table 2 summarizes basic properties for both types of aggregates. The data shown in table 2 is the average of two sets of measurement. Note that consistent data was recorded for all properties. The last column on

the right hand side shows the variation of the properties between virgin aggregate and RCA.

As can be seen from table 2, for any method used to measure the density (compacted or uncompacted for example), the density of RCA is typically 10% less than virgin aggregate. The water absorption is almost 10 times higher for RCA compared to virgin aggregate. These differences in properties are due to the old cement particles that are still pasted on the aggregate after it has been reclaimed from concrete waste. The density of the old cement is much lower than the density of aggregate. Cement is also a porous material and therefore it can absorb a larger amount of water than aggregate.

To reclaim the aggregate, chunks of concrete have been subjected to mechanical stress to extract the aggregate from the concrete block. This stress has damage the aggregate resulting in higher crushing and impact values for RCA than virgin aggregate. Also there is still some old cement paste stuck to the aggregate. When handling RCA friction occur between the aggregate loosening so fine particles of cement. That is why the fine (+50%) and sulphate (4 times more) contents of RCA are higher than virgin aggregate. The flakiness percentage is similar for both types of aggregates.

Table 2
Properties of coarse aggregate (virgin and RCA)

Specimen references		**Virgin aggregate**	**Recycled aggregate**	**Variation (%)**
Bulk density (Mg/m^3)	Uncompacted (as receive)	1.45	1.31	9.7
	Compacted (as receive)	1.56	1.38	11.5
	Uncompacted (oven dry)	1.46	1.29	11.6
	Compacted (oven dry)	1.53	1.38	9.8
Relative density on an oven dried basis (Mg/m^3)		2.6	2.34	10.0
Water absorption (%)		0.45	4.7	944.4
Aggregate crushing value (%)		17.7	28.7	62.2
Aggregates Impact Value (AIV) (%)		20.7	29.6	43.0
Fines content (%)		0.6	0.9	50.0
Flakiness index (%)		12	11	8.3
Total sulphate content (%)		0.13	0.66	407.7

PROPERTIES OF DRIED CONCETE

Table 3 shows the values of the averaged compressive strength of cubes (a minimum of two cubes were tested to failure) at 7 and 28 days. As can be seen, the strengths of the cubes made with RCA are typically slightly lower (maximum difference of 10.6%) than the reference cubes (without RCA). It can be seen that at 7 days, the strength does not seems to be dramatically affected by the percentage of RCA for mixes that use up to 60%. The compressive strength decreases by less than 4.5% for low to medium percentage of RCA. When the amount of RCA is increased to 80 and 100% the compressive strength decreases by 9.1 and 10.6% respectively. At 28 days the compressive strength of mix with 20% did not change. When 40% RCA or more is used the strength decreases by 7.3 for 40% RCA and 9.8% for 80 and 100% RCA.

Table 3
Cube compressive strength at 7and 28 days

	7 days		28 days	
RCA (%)	Comp. strength (N/mm^2)	Δ (%)	Comp. strength (N/mm^2)	Δ (%)
0	46.3	-	56.2	-
20	44.3	-4.3	55.7	-0.9
40	45.2	-2.4	52.1	-7.3
60	44.3	-4.3	51.6	-8.2
80	42.1	-9.1	50.7	-9.8
100	41.4	-10.6	50.7	-9.8

For harden concrete, it can be seen that typically the more RCA in the concrete mixture the lower the compressive strength. Nevertheless, all the mixes achieved the requirement of a grade 40 concrete.

PETROGRAPHY

From the visual observations of the specimens, the cement matrix was found to be light grey in colour and appeared homogeneous for all the samples. The coarse aggregate size ranged from 5 mm to 20 mm and was evenly distributed in the concrete. This is in good agreement with the particle size distribution of aggregate used in the concrete mixture. Neither segregation nor cracking were observed on the specimens. On the one hand, the entrained air concrete under fluorescent light was estimated to be

between 1.5 and 3% for all specimens. These values are typical for air content for concrete. On the other hand, Air voids caused by water absorption material were observed under fluorescent light for specimens with 40% and more of RCA in the mixture. These voids were created by the old porous cement that was initially dry; it therefore absorbed water from the fresh surrounding cement paste. Figure 2 shows the air void for specimens with 40 and 80% RCA.

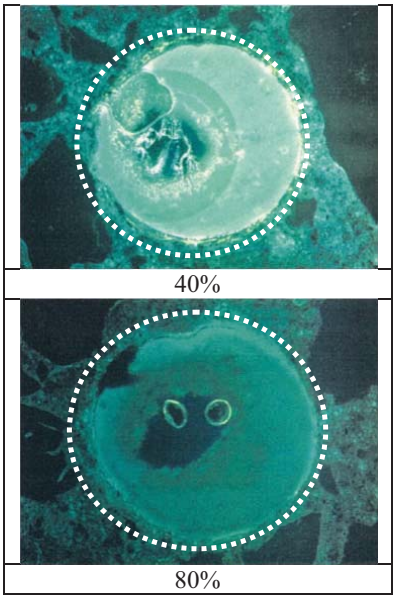


Figure 2 voids caused by water absorption material under fluorescent light

Observations at the interface between cement and aggregate shown that for low percentage of RCA, the cement paste and aggregate were well bonded together while as the percentage of RCA was increased the bonding quality changed to fairly bonded. No cracks were observed in any specimens. It was concluded that the bonding was satisfactory for all specimens.

STRUCTURAL BEHAVIOUR

Six specimens, i.e. one beam for each concrete mix, were tested one year (12 months) after casting. The cross-section was 200x300mm and 2xT25 were used as tensile reinforcement. The stirrups were Ø8mm mild steel spaced at 150mm. The top reinforcements consisted of 2xT10 rebars. The concrete cover was 20mm. The specimens were loaded under 4-point loading up to failure. The span was 4.5m and the distance between the loading points 1.5m. The hydraulic jack and the spreader beam were located above the specimen and the three LVDT's were placed below the beam (see figure 3).

The load increment was 3.5kN up to 21kN, i.e. approximately 2.5% of the theoretical failure load, and 7kN (5% of the theoretical failure load) above this value. The initial load steps were smaller to record more accurately the appearance of the first crack in the tensile region. Between each increment, the load was kept constant for at least 3 minutes before inspection of the specimen to monitor the crack pattern. The cracks that were highlighted on the specimen using markers.



Figure 3 experimental set up

Figure 4 shows a crack due to shrinkage of the concrete on the specimen made with 100% RCA. Therefore, it is important when large percentage of RCA is used to ensure that the concrete is kept in an appropriate environment during curing to avoid this type of cracks.



Figure 4 crack due to shrinkage on a the specimen with 100% RCA

It was observed that the first cracks appeared at a load of 17.5kN for mixes with 0 and 20% RCA, 10.5kN for the specimen with 60% RCA and 14kN for the remaining specimens. The mix with 20% RCA shown a better strength is tension than reference mix (0% RCA) as fewer cracks were found, i.e. 2 cracks instead of 7 for the reference mix. The first crack appeared at a load of 10.5kN for the mix with 60% RCA. The decrease in tensile strength may

be due to either by a problem of compacting, curing of the concrete or an inaccurate positioning of tensile rebars. Overall, it was found that the properties of the three concrete mixes with less than 50% RCA where slightly better in tension than three other concrete mixtures with more than 50% RCA.

Figure 5 shows the load displacement curves for the six specimens. In the legend, the first two digits represent the percentage of RCA in the concrete mixture and 12M means that the specimens were tested one year (12 months) after casting. The ultimate loads are extremely similar for all specimens. The slopes of the elastic region of the load-displacement curve for the specimens with 0 and 20% RCA are 15% stiffer than the slope of the specimen with 100% RCA. The stiffness of all specimens is similar except for the specimen with 100% RCA that shows a larger displacement for a specific load.

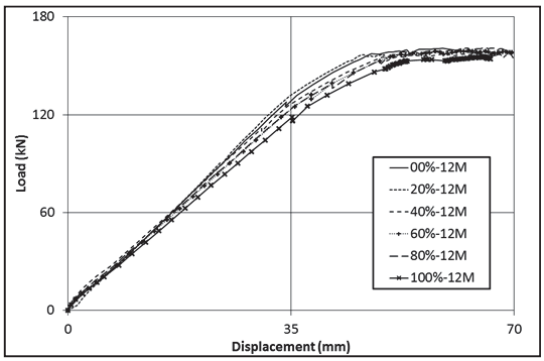


Figure 5 Load vs displacement (after 12 months)

Table 4 summarises the averaged compressive strength of cubes that were tested in compression on the day of testing of the beam specimen. As can be seen the compressive strength ranged from 59.9 to 65.4 N/mm^2 for cubes with 60 and 40% RCA respectively. Also after one year al the concrete mixes had a compressive strength well above the requirement of a concrete grade 40.

Table 4
Concrete compressive strength on day and failure load at 12 months

RCA (%)	Compressive strength (N/mm^2)	Ultimate load (kN)
0%	64.1	162.9
20%	64.4	159.6
40%	65.4	158.6
60%	59.9	159.2
80%	64.7	161
100%	63.4	155.5

The ultimate loads recorded for the beam specimens were between 155.5 and 162.9 kN for the specimen with 100% and 0% RCA respectively. The variation of ultimate loads between the reference specimen (0% RCA) and the one with the lowest coal capacity is less that 5%. This is due to the fact that the specimens were designed as under-reinforced and therefore it is the tensile strength of the rebars that affects the most the load capacity of the beam.

CONCLUSIONS

The investigation of the properties of the aggregate has shown that the mechanical properties, crushing and impact values for example, of the RCA were typically lower than virgin aggregate but within the limit accepted by standards (except the size distribution).

The water absorption was 10 times higher for RCA than virgin aggregate. This need to be considered when designing concrete mixture that uses RCA as the water absorbed by the aggregate will affect the workability of the concrete as well as its curing and finally its mechanical properties when harden such as compressive and tensile strength. Shrinkage of concrete may also be more important if the concrete is not cured properly and shrinkage cracks may appear.

This study has also shown that a concrete grade 40 can be obtained by keeping the w/c ratio constant and adjusting the amount the admixture even if 100% RCA is used in the mixture.

Similar failure mode and failure loads were recorded when beam specimens are subjected to 4-point bending. Typically, the deflection of the specimens increased with increasing percentage of RCA used in the mixture, which means that the stiffness of the specimen decreases. This had to be taken into consideration when designing structures especially if the limiting factor is the maximum deflection of the structural element.

For high percentage of RCA the number of cracks increased and/or the cracks were longer. Length and number of cracks may be of concerns when considering the corrosion of the rebars.

A crack due to shrinkage was found on the specimen with 100% RCA. Therefore, it is recommended that the concrete should be carefully compacted and cured when a high percentage of RCA is used in the mixture.

It can be concluded that RCA affects the properties of harden concrete and its compressive strength in particular. Nevertheless, the loss in strength is approximately 10% and is has been shown that the

required properties of a concrete grade 40 can be achieved at 28 days. In the Singapore context, it is possible to use up to 50% of RCA into fresh concrete for structural applications. The limit is set to 50% as more research is needed to investigate the shrinkage of concrete when RCA is used as well as the long-term effects of creep.

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INNOVATIVE AND SUSTAINABLE CONSTRUCTION PROCUREMENT PROCESS – AN EXAMPLE FROM THE UK CONSTRUCTION INDUSTRY

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ABSTRACT

Researchers have looked at the traditional ways of procurement within construction and identified the problems, and solutions in terms of better ways of working. Similarly, practitioners have informed the researchers their initiatives within the industry to bring improvements within the industry through innovative and sustainable construction procurement process. Supply chain integration research presented in this paper was one of the projects, which combined both the research and the practice within the UK construction industry in order to look at the effects of the sustainable ways of procuring construction projects, especially by the public sector clients. This paper will present some of the final findings from one of the four case studies carried out as part of the research within the UK construction industry related to the current practices and its effectiveness within the broader sustainable procurement process.

KEYWORDS

Sustainable, Procurement, Innovative construction procurement, Supply chain integration, UK construction industry.

INTRODUCTION

The recent moves with respect to procurement within the UK construction industry have resulted in sustainable, innovative and new arrangements of procurement. Recent policies by the Central Government have now being adopted by local authorities and other governmental organisations to ensure that the best value is achieved through these sustainable procurement initiatives for the wider public. Moves within the UK construction industry from the traditional way of procurement to the more sustainable and innovative methods including partnering, private finance initiatives (PFI), project alliances, framework agreements, prime contracting, etc. have already started realising the potential benefits (McDermott *et al.* 2004). The drive to change and promote innovation in the construction sector including how to procure in better and more efficient ways in order to bring improvements within the construction industry, was provided by government supported reports by Egan (1998, 2002) more than a decade ago. As a result of the Egan Report (1998), the Movement for Innovation (M4I) came into existence, which then helped different companies within the industry to realise the importance of innovation, and encouraged them to come up with innovative ways of procurement within the industry. The Egan Report, for example, stressed the importance of innovation within the industry, and proposed that continuous service and product improvement and company profitability can only be achieved through innovation. Other benefits include sustainability, improved leadership, customer focus, integrated processes, integrated project supply chain, improved quality, and firm commitment of parties involved.

The public sector has been seen to embrace sustainable procurement methods based on partnering concepts in last few years, following strategy documents such as Achieving Excellence (HM Treasury, 1999), and direction from both the Office of Government Commerce (OGC Report, 2003) and the National Audit Office (NAO Report, 2001). In the wake of the Egan Report, Rethinking Construction (Egan, 1998), which highlighted partnering as one of many options to improve the construction industry as discussed earlier, the UK Government Construction Client's Panel responded with Achieving Excellence (HM Treasury, 1999), which laid down targets for the number of projects which should be procured through integrated supply chain and partnering. This has been followed by the National Audit Office identifying new procurement routes based on partnering approaches as a key tool in delivering better public projects (NAO Report, 2001). It later followed this report up with a data that suggested that innovative procurement approaches, which tend to encourage sustainable approach, partnering and supply chain integration, had a demonstrable benefit within the public sector (NAO Report, 2005).

This paper will present the moves by a public sector client for implementing the sustainable procurement through supply chain integration in construction. The paper will also sum up some of the key findings from the case study analysis, to show that how this initiative is received by different participants of the supply chain within the industry, and how it has affected them, on individual,

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project, and organisation levels, and its effects on the overall construction industry.

INNOVATIVE PROCUREMENT

Let us look at the transition from traditional to best practice. In traditional procurement, projects are awarded individually and contractors have to submit tenders for each project separately, which then result into formation of a project based organisation or one-off supply chain where project participants are taken on board for that specific project (Oyegoke et al. 2009). Research shows that, in this type of procurement arrangement, when projects are completed, the supply chain partners usually disperse and move to other projects immediately, without giving enough time and attentions to post project reviews (Khalfan et al, 2010). Therefore, knowledge gained in the whole process is taken away by the individuals involved in the project, and in very rare cases become part of organisational knowledge for any of the companies involved (Khalfan and Maqsood, 2012). If those individuals are moved to a different type of project then their knowledge even does not get utilise on other similar projects either. Since, knowledge was neither captured, nor retained, nor shared, therefore, remains as a past experience in the minds of individuals with no productive utilisation. The new innovative procurement initiatives also take the above issues in account and bring solutions with it. Therefore, now the way in which work is awarded is changed from one-off project to a stream of similar projects, sometimes called framework agreements. Relationship of client and contractor has now moved from short term period to long term period with continuous flow of similar type of projects. The approach is moved from looking at project independently to the sustainable development of the community. This has also resulted into change in the structure of project team, which in traditional model, work on one project and usually called project-based organisation, to a set of partnering organisations which would now work together with each other on a long term bases on several projects, usually called integrated supply chain (Khalfan et al, 2007).

The author observed during the case study reported here, that as far as adopting innovative and sustainable procurement strategies and partnering concepts are concerned, the case study participants demonstrated great motivation to move from adversarial relationships to more collaborative ones. The basis of all these innovative relationship models is the concept of partnering, resulting in the development of trust (Latham, 1993; McDermott *et al.* 2005), and long-term collaborative and integrated relationships among different organisations throughout the supply chain (Khalfan *et al.* 2001). Cox and Townsend (1998) define this relationship as follows:

'Partnering is a long term commitment between two or more organisations for the purpose of achieving specific business objectives by maximising the effectiveness of each participant's resources. The relationship is based on trust, dedication to common goals and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and service.'

In the UK, the National Audit Office (NAO report, 2001) has endorsed the public sector moves away from lowest cost and adversarial approaches towards the newer forms of procurement. In particular, it calls for the entire supply chain, including clients, to be integrated. Through Achieving Excellence (HM Treasury, 1999), the Government had already committed all government departments to:

- To work with industry to reduce waste in all aspects of construction procurement and management;
- To enter co-operative relationships with their suppliers to ensure an open and mutually productive environment, and
- To ensure an integrated supply chain.

The case study presented here is from a project which investigated the changes that are occurring in the supply of consultancy and contracting services in response to innovative client procurement initiatives and their sustainability agendas. It is particularly timely now with not only private sector clients, but public sector clients being driven towards sustainability through partnering. The main aim of this research was to determine if there were ways of integrating the supply chain that will ensure sustainability, and service and product quality whilst still supporting the government and client initiatives, aimed at increasing the competitiveness of the construction sector. Specifically this project has the following broad objectives:

- Identify current international and national best practice in sustainable procurement and supply chain integration;
- Reveal the critical success factors for the establishment of effective and efficient supply chain integration – the behaviours/ responses to the new means of procurement made by successful firms in innovative supply chains; and

- Test the proposition that the effective configuration of long-term supply chains will be different for different kinds of construction.

THE CASE STUDY

The case study presented here attempted to uncover the perceptions of firms within the construction industry with regard to the existing partnering arrangements they currently undertake. The research used multiple methods to collect qualitative and quantitative data. Basic quantitative data and company documentation were used to provide research context while qualitative data, collected in the form of a number of unstructured interviews, sought to understand how innovative procurement was viewed by different supply chain partners. The case study approach followed the protocol developed by Yin (1994) in order to improve the validity of the research. As a result, the research included a number of key elements such as clear and concise research objectives, research propositions, case study selection criteria, unit of analysis, a structured questionnaire, semi-structured questionnaire for interview, a predetermined case study procedure, and an interview guide (Yin, 1994). The study involved multiple visits to each organization involved, including an average of three interviews with the Managing Directors of these companies and other staff and a few other interviews with their supply chain members in North West of England. All interviews lasted for at least 1 hour. An assumed name for each company has been adopted for the purpose of confidentiality, when reporting the case study.

One of four case studies from the project is reported here. The case study explores the initiatives taken by a public sector client to motivate main contractors and their supply chain participants to adopt sustainable and innovative ways of working within a project team. The senior management of each of the above-mentioned organisations was interviewed. Soft System Methodology (SSM), along with case study research method, was used to analyse the interviews, used for organisational analysis. For the social and organisational aspects, the research drew on contextually rich modelling techniques of SSM (Checkland, 1981) with its emphasis on a stream of cultural analysis within construction organisations, and the industry overall. The SSM was selected because the research was dealing with the softer social issues and phenomena such as changes in the behaviour of people and companies in response to the changed in procurement routes. The whole idea to adopt soft system methodology was to carry out this qualitative research revolved around the advantages of using SSM. Once the interviews were carried out, the rich pictures were developed and these pictures helped us to identify the issues and areas which have been affected by the change in procurement strategies. The root definitions and CATWOEs were then developed from the rich pictures which helped us to understand the transformation of past situations and circumstances to the present scenarios. Some of the results are reported in this paper as observations of changes due to the innovative and sustainable procurement, and motivational issues affecting the adoption of newer ways of working.

The case study was done with a public sector client, a local council, which had developed a Framework Agreement to construct educational buildings (primary school in the first phase) in the value range £500,000 to £5 m. For this client-led innovative and new way of developing educational infrastructure, which basically aims at the process of getting product developed, three Constructor Partners were appointed in 2004 for three years initially.

BENEFITS FROM THE INNOVATIVE FRAMEWORK

The core values of framework agreement, which are based on the partnering concept, agreed by the client and all other participants, include: Trust; Honesty; Openness; Commitment; Co-operation; and Respect. The council's vision was that this framework agreement would deliver sustainable and good quality school buildings that will lead to (Khalfan and McDermott, 2006); Better

educational results; Greater inclusion within the community; Better safety and environmental performance; and Reduced demand on future school budgets by addressing whole life cycle costing at the inception of the projects.

The major benefits were achieved in the following broad area by adopting the above mentioned strategic partnering framework for the development of Primary Schools; Improved design to overcome environmental issues; Less waste and duplication; Improved delivery; Greater quality; Hiring of local subbies and suppliers; On the job training for locally hired staff; Greater certainty of cost; Better whole life cycle costing; Building of trusting relationships; and Bringing of all "project knowledge" together at the inception of a project.

EXAMPLES OF INNOVATION

The council changed the mechanism of selection for contractors and sub-contractors. It used to be the case in the past that the small companies were rejected based on their turnover. Now the turnover figure was not used as part of the selection criteria and was only considered afterwards when the percentage of the work was being allocated. Therefore, those companies, which used to be left out (specially the local SMEs) because of their small turnover, were now able to pass through the initial two-stage selection process of the council, and then they were awarded work which was equivalent of 25 % of their turnover (irrespective of how much it was!). On the other hand, the selection was now moved from traditional to Quality-Price Mechanism. The council used 70% - 30% respectively for the selection. The council also used a specific quality and performance criteria to select the companies for the framework agreement during the selection process.

The findings show the move by clients in general, and especially public sector clients as mentioned above, from accepting the lowest bids to awarding contracts that show best value. This is termed as price-quality mechanism in some cases, where tenders are judged based more on the quality than price. This has enabled the clients to look at previous or ongoing construction works of the contractors in order to verify the quality, in addition to the references. This is one of the major findings during the case study, which shows that more and more clients, and contractors for the selection of their supply chain, use pre qualification questionnaire (PQQ), which includes questions related to sustainability, quality, health and safety, turnover, references, etc. Some other examples of innovative thinking to integrate supply chain are listed here:

- All three contractors had come up with an integrated supply chain for the 1st tier including the Design team and M & E Contractors. They all involved with the client to develop the plans for the school development.
- Introduction of post-construction Snag Period (12 month) would reduce the complaints from the end users (head and building in-charge of the schools), resulting into much better response and solution to any problems occurring in the school building.
- Client driven initiative, which is bringing all the parties involved including three main contractors, resulting into sharing of knowledge and experiences on different platforms including project meetings. Innovation within the construction was that representatives of all three contractors used to sit down together for selecting the standardised material e.g. windows, doors, etc.; architects of all contracting organisations working together to learn from each others' design experiences; and the learning from one project within the framework was taken forward to the new projects through capturing the experiences and feedback of the people involved by all three supply chains.

EXAMPLES OF SUSTAINABILITY ISSUES

The council looked into sustainability aspect in the following manner during the procurement process:

- Design team for each contracting organisation was charged to come up with the innovative design which takes account of the use of natural light and ventilation, as well as recycling of grey water for toilet flushes. There were also other environmental features considered by the designers including use of recycled material such as bricks for the façade etc.
- The main contractors were required to hire local sub-contractors and suppliers for the projects in order to contribute towards economic growth of the local community where the schools were being built.
- Local people were hired to work during the construction of these schools in order to contribute towards social and economic growth of the area. Committees were formed with local representation for consultation and on the job training was provided to local young adults are their entry point in the industry.

FINDINGS AND GENERAL CONCLUSION

Some of the findings from the above case study are listed below. The findings refer to the best practices done at the under consideration organisation:

- Strong and committed leadership from client was observed to introduce sustainability aspects within the procurement process;
- Firm commitment of the main contractors was seen vital to adopt sustainability agenda and integrate the supply chain;
- There was a true understanding of what does 'partnering' mean by the entire supply chain participants;
- Long-term relationship among supply chain members, which was due to trust and open communication;
- Processes were in place to incentivise for good performance as part of the supply chain;
- Appropriate strategies were in place for main contractors to use local suppliers, subcontractors, and work force;
- Strong commitment of clients and main contractors to invest in training and development of their supply chain organisations;
- Innovative design solutions were produced to overcome environmental sustainability issues;
- Early payments of services provided was observed;
- Learning was taken from one project to the new projects;
- Improved KPIs resulted into more integrated supply chain;
- Support was provided from main contractors to their supply chain partners if any one of them are in troubled water either financially or skill shortage-wise, etc;
- All supply chain participants were practicing the partnering ethos both in the office as well as on construction and development site; and
- Local companies and people were hired to work on the project, contributing towards economic and social aspect of sustainability.

LEARNING FOR TROPICAL COUNTRIES

Some of the key learning which we could take from the above mentioned case study are listed below:

- Sustainability aspects should be part of entire development process rather than thinking about it – built in rather than bolt on;
- Sustainability targets should be defined earlier in the process and plan needs to be in place to achieve those targets;
- Performance of the key players contributing towards sustainability agenda should be monitored on regular basis;
- Adoption of define processes to support implementation of sustainability agenda;
- Use of procurement to make sustainability requirements part of the contract with the supply chain partners;
- Firm commitment of the senior officials of organisations to upload the sustainability agenda;
- Collaborative environment among the supply chain participants to promote sustainable construction practices within the industry;
- In addition to collaboration, there is also need for supply chain integration to integrate different processes to achieve sustainable development outcomes;
- Whole-life costing should be given preference over initial cost of any facility design and construction; and
- The entire community is seen as the beneficiaries of such initiatives with outcomes to promote sustainable social and economic growths.

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