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W108 - CLIMATE CHANGE AND THE BUILT ENVIRONMENT

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All aspects of building performance, where these are affected by climate change, would come within the scope of the Commission and its membership would therefore be expanded to embrace not only environmental researchers but also those dealing with materials, structures and construction operations. There would be a need to have strong interactions with other Working Commissions dealing with these specialist areas. The Commission Objectives are: to provide a forum for establishing the exchange of weather data, climate change scenarios, research findings and formulating joint research projects on the impacts of climate change on construction and the built environment, and measures to anticipate and ameliorate such impacts, to facilitate the transfer of data and research findings to practitioners, in particular to influence building design and adaptation, the revision of relevant standards, codes and specifications so that these reflect potential impacts of climate change and to be a vehicle through which funding for collaborative research into the impact of climate change on the built environment might be secured.
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Approaches to Develop Sustainable, Climate Adapted Buildings for Japan as a Subtropical Climate Case

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Abstract

The study addresses the need to develop overall designs and concepts for houses that are tailored to culture and climate in order to sustainably reduce emissions from the building stock. It focuses on subtropical climates and Japan as an example for such conditions. The general method used is balancing initial ecological and economical costs (such as CO$_2$e emissions or aggregated indicators) with running costs to assess the life-time performance of concepts also taking into account frame conditions like users’ acceptance and culture. The method is applied in a project in Japan from which the first preliminary experience values and results stem from. Calculations for the Japan case show that the optimal balances for economical and ecological costs match quite well for this country. Concepts concentrating on the envelope in order to cover and reduce the energy demand by passive means are tending to show lower environmental costs while concepts concentrating on the heating/cooling system tend to show lower economical costs. A sensible compromise can be found between these two aspects optimum. The reason is to be seen in the low interest on the one hand and the lack of alternative energy generation measures on the other. The necessary make-ups for the wall from the building physical viewpoint also match quite well with the evaluated concepts. The concepts that are now realized in Japan by far surpass any currently established efficiency and therefore are met with scepticism at the moment. In the first discussions with local building companies and customers the increased comfort and the provided healthy living prove to be far superior arguments that the original focus on an overall minimum of environmental and ecological costs. Barriers to be overcome in the next years are mainly to be seen in the current focus on initial investments on part of the customers, neglecting the life-time costs and therefore resulting in concepts that are not optimal when evaluated over the complete lifetime. Also many concepts still have a very strict viewpoint on how a house has to look like, often being inspired by concepts that come from completely different cultural and climatic conditions.

Keywords: sustainable building concepts, Japan, subtropical climate, life cycle balances, climate adapted concepts
1. Background

1.1 General

The challenges of reducing their overall CO\textsubscript{2} e emissions confront many countries with the need to reduce the emissions from their building stock, as emissions from this source often equals about a third of the overall amount. (Lomas 2009) Contrary to other areas where savings often come hand in hand with demands for sufficiency which would reduce the living standard and comfort of the people in question, the building stock can be seen as one of the rare cases where saving of emissions and a raise in health and comfort accompany and complement each other. The reason for this is that many countries with poor quality houses suffer from sick building syndrome due to mould and condensation phenomena in the buildings. Increases in the quality of the building envelope also result in more comfortable inside conditions by creating surface temperatures. (United Nations Environment Programme UNEP 2007)

Because of the reasons above the field of energy efficient building technology is understood by many companies as a very promising export market. In several countries there are solid experience values with energy efficient houses and the required technology. These obviously qualify for export and have the potential to have a huge impact on the energy consumption of buildings in the receiving countries and therefore the emissions.

However many such approaches in potential markets are met with failure. There are two main reasons for this:

- There are often no solid evaluation of the local needs and demands. This would include knowledge of the local living style, the culture, the acceptance of a technology as well as taking into account the necessary infrastructure to run a technology. Many frame conditions that are existent in the source country are taken for granted in the approached country as well. The result of such mistakes is often a technology that is not accepted, used incorrectly, cannot be supported or implemented into the local conditions.

- The technology to be exported is introduced without the necessary overall concept that is required by it to perform well. The results are often damages to the technology or severe reductions in its performance and efficiency up to the point where it loses its emission reducing value completely.

Out of the many countries that emit huge amounts of CO\textsubscript{2} emissions due to their consumption in buildings some are of special scientific interest as they have very challenging demands for a low emission buildings and implementing a new technology is most difficult. These countries have climates that are summed up under the overall term subtropical climates by meteorology. From the viewpoint of architects they have heating as well as cooling demand. From the viewpoint of building physics the humidity stream inside the outer walls changes direction in the course of the year. From
the viewpoint of the social scientist many of these countries have customs and a lifestyle that completely differs from the western one. It has to be noted that some of the countries with the fastest growth of CO₂ emissions are in subtropical climates. (Raupach, Marland et al. 2007)

The following map gives an overview of the countries addressed:

![Map of countries](image)

Picture 1: Relevance of the subtropical characteristics for the housing design (Based on Köppen-Geiger climate definitions) / from relevant (dark) to irrelevant (bright)

1.2 Japan

Besides the challenges of the local climate Japan offers some conditions that make it ideally suited as a starting point to test and optimize methodological approaches as well as technologies and concepts for subtropical climates.

Japan has severe problems with its building stock. The complete traditional knowledge of designing climate tailored buildings was lost in the Second World War. Afterwards influences by western oriented construction methods dominated traditional knowledge. These imported and new building systems where never adapted to the cultural and climate conditions and therefore suffer from building physical problems of all kinds. Especially the residential buildings and one family houses, mostly wooden structures are problematic in this regard. The average lifespan of such a Japanese dormitory is about 20 years, afterwards it is torn down and a new one is build. About one million Japanese are currently registered by the Ministry of Health, Labour and Welfare as having illnesses that are the direct result of their living conditions. The economic demand for solutions to these problems by designing buildings that are free of mould and condensation and therefore also have a lifespan of much more than the currently accepted 20 years is huge. The necessary knowledge to design and build such houses is not existing in Japan at the moment. While there are often several chairs that are conducting research on earthquake resistance measures at a Japanese university, the field of building
physics while existent so far has no influence on the building industry. The potential for a simple know how transfer seems to be enormous.

On the downside Japan has a very restrictive market. This shows in the complex and time consuming steps necessary for getting a license for a technology in Japan in the first place and later in a general scepticism of the customers concerning foreign products.

While being liberal in many markets, especially those with direct international competition, the housing sector is especially conservative. The reason for this is to be seen in the market structure of the Japanese building sector. It is dominated by several big housing companies, sometimes building several 1,000 houses every year, in contrast to the more individual oriented system using small architects’ offices that is common in Europe. The big Japanese companies have a huge infrastructure, including prefab branches, material producing branches and engineers. As a result they are slow to change their houses concepts, as it would include massive changes in their infrastructure as well. With most of the job training taking place within the companies and not at the universities a huge effort for schooling the employers would also be necessary, resulting in enormous costs.

Middle sized companies on the other hand would have the ability to change more quickly. They are however at a severe disadvantage on the market, as the customers give huge advance of trust to big corporate groups. In times of the economic crisis the same is true for their chances to get funding for initializing own and innovative projects. From the viewpoint of the funding organizations they are often simply not competent enough to conduct such projects. As the big corporate groups are not willing to move the market the change however can only come from these middle sized actors.

Concerning the problems listed above the Japanese market is a prime example. Because of its attractiveness many companies have tried to introduce building material or technologies without adapting the concept/technology and doing solid research on culture and local needs. All of the approaches focusing on the envelope failed, resulting in low quality building hulls with a sophisticated heating and cooling system without a sound overall concept. These two fields of technologies do not complement each other but rather work against each other in many cases, resulting in mould and low comfort. As another result running consumption and initial effort are not balanced. This creates a situation where the vast majority of buildings are wasting energy due to unnecessary large running consumption. On the other side there is a minority of buildings introducing concepts from abroad that have low running consumption but levels of insulation and therefore initial environmental costs that are not sensible in subtropical climates or window fractions that are oversized for reducing heating demand due to solar gains instead creating more cooling demand in summer.

From the scientific viewpoint Japan offers a unique opportunity: because of its extreme shape, stretching from north to south, Japan encompasses several climate zones in one country and therefore one legal condition and culture. Therefore concepts for climate tailored designs can be evaluated for several climate conditions within one country and culture. The following picture shows the distribution of the climate zone in Japan from cool temperate Hokkaido to the subtropical climate of central Japan and Kyushu:
1.3 Holistic approaches

The current state of knowledge concerning sustainable approaches to counter climate change names three important aspects to ensure a truly holistic solution: social sustainability, economical sustainability and ecological sustainability. Such an approach would also prevent a technology from failing in a given country due to the under background given reasons. To implement technologies for reducing emissions in Japan it is necessary to first design a truly sustainable overall concept implementing promising technology and tailoring it to the local needs. Such a demand for a concept that is climate adapted and fit for the future, combining new technology with design issues, however is leading to a lot of questions:

- In a country where a new concept is to be introduced there are no experience values with the user behaviour yet. While certain guesses can be made a huge uncertainty has to be seen here. A solid evaluation of the impact the concept has on the way of living is surely mandatory.

- The general acceptance for technological solutions is often not clear. In some cases it mainly affects active technologies; in some cases it mainly affects passive technologies. For both cases there are cultures and cultural subgroups that are extremely hesitant to employ a certain solution because it does not feel right for them. Solid exchange with the people in question is mandatory.

- Regional problems that are only indirectly connected to the building often offer huge potential for acquiring local acceptance and improving the environmental performance of concepts. A solid research on the local problems beyond the core building industry is often extremely valuable.
When starting the design process the order by which the measures are applied has a great impact on the result. When the design is started from small to big measures (controls to design) the outcome is most often a building that is centred on flexible application of the housing services and movable elements at the facade. When the design is started from big measures to small measures (from design to controls) the result is often a traditional inspired design where the heating and cooling system is focusing on covering the peak demands. Both design strategies surely have their potentials and advantages, to be reflected in front of the local situation.

Most important the evaluation of a solution should not be reduced to the usage phase, though it is often dominant (Sartori and Hestnes 2007). When designing houses that come close to fulfilling the requirements of international targets like 1 ton CO₂ per capita and person or the derived 2000 Watt Society the initial effort needed to produce the building materials contributes an important part of the lifetime emissions. The current state of knowledge allows the calculation of this part if the associated companies provide information on the related production procedures. The increasing availability of this data in combination with more and more reliable calculation tools for the running consumption allow for the calculation of overall life cycle performances and therefore the possibility of balancing measures to achieve and optimum overall performance. (Spreng 1995)

2. Method

Basically a building can achieve a comfortable inner room climate by passive (internal and solar gains in combination with a well designed envelope) and active means (heating or cooling system):

Graph 1: Combinations of active and passive systems to cover comfort

While in theory comfort can be created by either approach alone, almost all concepts use a combination of active and passive means to reach an overall sound solution. The reason for this is that the effort for active and passive measures increases disproportionately in concepts that rely mostly on one of them. Approaches solely relying only on one of them (a campfire) can also fail to provide comfort. The basic dependency is shown in the graph below:
Graph 2: Accumulated costs of active and passive systems to cover comfort

When comprehending a house as a combination of active and passive measures, the main question when developing a house for a certain climate is which combination is resulting in the optimal overall lifetime performance. Such an optimal solution is described in the graph below:

Graph 3: Optimal solution for a given Indicator and reasonable solutions based on optimal solution

Of course the results will differ based on the frame scenarios (development of scarcity, interest and resulting costs) and the indicator chosen (CO2, money, energy, UBP). Together with information on the user acceptance concerning passive and active measures in between the optimal solutions for one given indicator sound overall concepts can be developed.
Graph 4: Optimal solutions for different indicators

The regional energy generation (both for the running consumption and the creation of the materials in the first place) and the interest for investment money for financing the building of a given project are the main factors for influencing the optimal combinations. Lessening the interest on investments allows for more initial investment in efficient heating or cooling systems and the envelope, therefore reducing running consumption. An adapted, ecological energy generation or energy mix can counter individual ecological costs in terms of life cycle assessed indicators such as above.

Besides helping to decide on a sound combination of active and passive measures, the method can be a tool to develop proposals for the local decision makers where to create the biggest impact when investing money in the local infrastructure to decrease environmental damages.

3. The first project in Japan

3.1 General information

The University of Tokyo, the EMPA and the ETH Zürich are currently working on a project to develop sustainable houses in Japan and start an ongoing know-how transfer between Switzerland and Japan. The project is funded by the Swiss government due to the Commission for Technological Innovation (CTI/KTI) as an export opportunity for Swiss building technology is seen based on the results of the cooperation.

On the business side of the project Japanese building companies will cooperate with partners to bring the concepts to the Japanese market. The Japanese companies will be schooled in the technologies and concepts in the coming year in theoretical workshops and on the building site. This process, during which also the concepts are further fleshed out based on the feedback of the cooperating Japanese building companies, the first test buildings will be constructed in Sendai, Tokyo, Kyoto, Nagoya and Kanazawa. These buildings will be evaluated on their performance and used for promotion measures.
First buildings using some of the materials used in the overall concept have already been realized during the last years. As acquiring the licence especially for structural elements is extremely hazardous in Japan it made sense to separate the single components during the licensing phase.

![Building Site Pictures](image)

**Picture 3** : Pictures from the building sites necessary for acquiring the licence for the employed structural elements in Japan

Besides a focus on the hygro-thermal modelling of the materials used in the building envelope and accompanied testing of promising solution in climate chamber tests to avoid any humidity damages in the first test buildings the design approach is covered by the method above. For the frame conditions in Japan there are therefore first preliminary results concerning the feasibility of the approach as well as practical experience values.

After the evaluation of the performance of the first test houses, there will also be data on the correctness of the assumptions made during the calculations.

### 3.2 Preliminary results

#### 3.2.1 Feasibility and results

The approach of balancing initial effort with running consumption is in many cases met with an overwhelming acceptance. The architects and building companies are relieved to be approached with concepts that are made for their market instead of just being proposed a copy from another country, climate and culture. Their very Japanese viewpoint of seeing Japan and its frame conditions as something very special, not comparable to other situations in the world also supports the approach chosen in the project.

While the argumentation that buildings look different, depending among other factors on the climate conditions and culture, is understandable at once, there is currently no calculation approach to apply this knowledge and implement it into the design process. Balancing the initial costs and resulting running costs of the most influential active and passive parts of a building to achieve an optimized overall performance is in this regard a promising first step.
Problems arise from the fact that especially the data on Japanese building materials is insufficient. Japanese production companies often fear that the information they would have to provide will lead competitors to copy their production methods. This kind of thinking has led to the situation that the environmental impact of the production of Japanese building materials is difficult to assess and very often (because of lacking interest and competition) very inferior to international competitors. Considering the global market of building products this makes importing building materials an alternative for the short term. Improvements could surely be created by establishing more sustainable local production processes of course. As a side aspect the calculation model gets increasingly complex the sources of energy generation are to be included. The creation of insulation material with a very efficient energy production in one place, while using a very environmental damaging means of covering the running consumption is an example that can lead to very extreme results, especially concerning the environmental indicators.

As a result of importing many building materials (for the envelope) the optimal combination of passive and active components moves towards a more active concept. For central Japan, differing based on frame conditions and local energy generation, sound insulation thicknesses are in the area of 10 to 14 cm in combination with extremely sophisticated air based heat pump systems from Japanese Manufacturers. While ecologically optimal concepts (with local production lines) are in the range on 20 cm, the short term solutions are within 25% of the optimal ones. In all current concepts sophisticated two layered glazing performs better than three layered glazing in central Japan, especially when combined with adaptive shading measures.

A general problem is that for calculating the running consumption a certain user behaviour has to be assumed. As there are only experience values with the Japanese user behaviour in very low insulated houses without wind tightness, these assumptions are more or less good guesses based on experience values in other cultures and climate. Derivations from the assumptions made of course change the results of the calculations.

When comparing the optimal concepts for different indicators the difference is surprisingly small. In contrast to calculations for Switzerland and Germany, where economical indicators tend strongly to low initial investments and higher running consumption while ecological indicators show an opposite demand, Japan shows a much smaller difference. The reason for this is to be seen in the nearly not existent interest from sides of the banks for funding building projects especially for building companies and private customers. The constant demand of sustainable technology in Europe to compete with the possible earning by putting the money at the local bank, respectively the money consumed by paying off the interest from a credit taken does nearly not exist in Japan. This should lead to very ecological solutions and concepts; however this is not the case. The roots for this situation are however to be seen in social conditions, for the possible application of the method the situation is a strong point.

### 3.2.2 First field experience values

Besides the scientific feasibility of the approach and the creation of acceptance on the Japanese part, the method has been found to be absolutely no selling point. This is even though the proposed
concepts beat the established concepts by factors in their associated life cycle costs. Japanese customers tend to view their home as a consumption product. The initial investment is all they look at. The main selling points were proven to be in the field of health (as the concepts can be proven to be free of mould due to dynamic modelling) and comfort (as a well designed and insulated/ wind tight house offers comfortable inner climate).

As a surprise during the building process of the first buildings for licensing the single materials to be employed came the complete lack of communication and understanding between the craftsmen responsible for different tasks of the building processes. As a result the interchange between the employed building technologies is not looked at or even realized. The culture practically forbids talking a professional into his business unless specifically asked. As the respective professional does not know what questions to ask some irrational solutions are never solved. One of the key reasons for this situation is the near complete lack of building physics in the Japanese building industry. Most damages arise in situations where a building physician would be the responsible expert. Due to him being not existent the problem persists. Examples for this are condensation phenomena and aspects of wind and air tightness that would lead to a demand for modified detail solutions.

The interchange between performance and detail solutions generally is on a low level. That a concept demands a resourceful planning and realization is only applied to earthquake safety where highest standards are met. Where energy savings and emission reduction comes from is not realized. The general quality on Japanese building sites and the exactness of their building processes is on an extremely high level though. Even solutions that were thought to be difficult to apply on site due to building site conditions were easily realized with overwhelming exactness. What is lacking is the realization of what factors are important and why they are.

The above mentioned focus on concepts that only use 10 to 14 cm of insulation is often an advantage when talking to Japanese customers. As the established homes often have only 4 cm of insulation, convincing them of using 20 cm is difficult. 10 to 14 cm is for them the limit of rationality.

A great advantage is the focus on building materials that can in middle terms be produced using local regenerative resources. As there is need to utilize a large amount of small sized woods which come from forest improvement and are regarded as not strong enough for applying as structural elements of buildings, any use for this resource is appreciated. The Japanese building industry, currently suffering from the economical crisis, is also much more attracted to concepts that provide long chains of value generation and employment within Japan.

## 4. Outlook

Besides the outstanding evaluation of the first test buildings, allowing for a sharpening of the assumptions made especially on the user behaviour, two points are to be optimized in the next years:

- Although the approach is promising, the calculation processes is hazardous at the moment. Contrary to the smooth graphs shown under method, the process currently consist of
calculating several concepts (some focussing more on active and others focussing of passive means). Afterward the fine-tuning is done by changing insulation values and other building physical characteristics. A software based tool that would allow to easily model the effect of changes and different scenarios is under development.

- Even when first evaluation of the test buildings provide a clearer picture of the Japanese user behaviour and is changes in better buildings the findings will hardly be representative. The first customers under related circumstances in other countries are mainly people with a high awareness for ecological issues and are not mainstream customers (Steemers and Manchanda 2010). In the next years when the cooperating Japanese companies will start diffusing the market, broader studies on the user behaviour will be mandatory.

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References


Climate Change Risk Management for Buildings

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Abstract

This paper reports on research that aims to quantify the thermal risks that climate change poses towards buildings, allowing a discussion about the acceptability of these risks. The work aims to ultimately establish risk threshold values, helping the facilities management processes. The paper reports on two different but interrelated research activities: (1) work in the field of building performance simulation, where computer models are used to predict the thermal behaviour of buildings under present and future conditions, and (2) a recent series of workshops/expert panels that were organised to discuss initial findings with actors in practice as well as academia. The results show that building simulation can indeed be used to predict future behaviour, but extreme care is needed in preparing the detail of the future scenarios that are being investigated. This covers non-trivial issues like uncertainties in renovation/intervention activities, changing heat load and user profiles, thermal comfort control assumptions, and system degradation. Without sufficient attention for detail uncertainties over the simulation input would render the outcomes useless. The expert panel sessions confirmed the need to involve stakeholders in the building operation/facilities management process in climate change impact research; without these stakeholders it would be nearly impossible to identify the key performance indicators that need to be investigated. Overall, the work demonstrates the limits of a purely computational approach to studying the risk posed by climate change to the thermal performance of buildings, stressing: (a) the need to study specific situations in detail through actual case studies; (b) the need to involve stakeholders in those studies; and (c) the need for further research in the ‘soft’ factors that influence the facilities management process.

Keywords: climate change, risk, thermal performance, facilities management, simulation
1. Introduction

Buildings are an area where climate change poses risks. Most buildings have a long lifetime, which means that buildings will be in place long enough to experience the slow process of climate change. Moreover, the thermal performance of most buildings is strongly intertwined with the climate in which the building operates, which is a dominant factor in heat flows due to transmission and ventilation. Also note that climate conditions are a prime factor in the applicability of some of the heating, ventilation and air conditioning systems applied in buildings such as summer night cooling or natural ventilation.

Research in the adaptation of buildings to a changing climate is only recently appearing. In the UK the seminal work in the discipline is the report by CIBSE TM36 on Climate change and the indoor environment: impacts and adaptation (Hacker et al., 2005). Examples of more recent work in the field include the studies by Crawley (2008), Jenkins et al., (2009) and Coley and Kershaw (2010). While these studies provide valuable insights into how buildings will cope with changes in climatic conditions, they are not yet addressing the actual management of buildings subject to climate change by building owners, occupants and facility managers. Such management will weigh risks and investments, defining the building operation and deciding upon interventions in the building services, fabric (infill, cladding) and structure.

In general risk can be calculated according to the following, universal formula:

\[ RF = Pf \times Cf \]  

Where RF = Risk Factor, Pf = Probability of failure, and Cf = Consequence of failure. Calculation of RF allows to set thresholds to identify low (> x), medium (> y) and high (> z) risks, and highlight those risks requiring further attention.

This paper describes research that aims to quantify the thermal risks that climate change poses towards buildings, allowing a discussion about the acceptability of these risks. The work aims to ultimately establish risk threshold values, helping the facilities management process.

2. Methodology

The paper presents work in two related lines of work: building performance simulation research, and expert panel workshops.

The international building research community has been studying the thermal behaviour of buildings since the energy crisis of the 1970s. Since then, it has developed a large number of methods and software tools to analyse and optimise thermal building performance. These tools are now used in building engineering on a regular basis. For good overviews of the related field of building performance simulation see Malkawi and Augenbroe (2004) or Clarke (2001). Building simulation is
the only available methodology to predict the impact of future climate conditions on the thermal behavior of buildings in detail, since it can conduct a ‘virtual experiment’ in the computer that combines climate predictions with physical models that represent how building will respond to these future conditions.

However, work that aims to study the management of buildings and building systems (like for instance building services and building fabric) also needs to take into account the operational context of facilities management. To cater for this need, a number of expert panel workshops have been organised to discuss simulation results with colleagues from practice and academia. The format of these workshop sessions was a half hour presentation on the building simulation studies, followed by 45 minutes of discussion and feedback from the audience on the ongoing research.

3. Building simulation studies

Building performance has been based on the use of recent releases (V3.0-V4.0) of EnergyPlus. EnergyPlus is a well documented and validated simulation engine, for documentation see the EnergyPlus website.

Simulations have been carried out for two buildings: a theoretical reference building, and an actual existing building.

The theoretical reference building is based on the specific case as defined by CIBSE TM36 (Hacker et al., 2005, pp.42-43) “O2: Modern mixed-mode office”. This case represents a modern medium-sized office building with mechanical mixed-mode ventilation and low-energy active cooling. It is a three-storey office with a floor area of 3864 m², as depicted in Figure 1. The building is well insulated, with overhangs to shade windows in summer, and has ample thermal mass for heat storage. Schedules for lighting, equipment and occupancy are according to the British data for an open plan office as described in the National Calculation Method (NCM, 2009). In winter, mechanical ventilation with heat recovery is used to provide the air for the building, with all 100% sourced from outdoors. In summer, there are two ventilation modes: natural and mechanical. The natural ventilation (free-running) mode is used when the indoor operative temperature is below the cooling set point (below 25°C using the static thermal method, below a variable threshold when using the adaptive thermal method). Otherwise, mechanical ventilation with an indirect evaporative cooler is used to provide sensible cooling for the building without increasing its absolute humidity (CIBSE, 2005). In the simulation, the natural and mechanical systems are in changeover operation mode, which means they do not operate at the same time. The mechanical ventilation system is also used for night cooling in summer. It is noted that this office building may have overheating problems as the indirect evaporative cooling has only limited cooling capacity (ASHRAE, 2008). More detailed descriptions of this office can be found in literature, see Hacker et al. (2005) and Holmes and Hacker (2007).
The TM36 O2 Reference Office has been studied using the UKCIP02 climate change scenarios as released in 2002. These have become the standard reference for climate change research in the UK, accounting for four emission scenarios (low, med-low, med-high, and high). Three 30-year time slices have been used: 2011-2040 (2020s), 2041-2070 (2050s) and 2071-2100 (2080s).

Within the simulations, a range of uncertainties has been covered by means of 2-D Monte Carlo analysis. Distinction has been made between aleatory uncertainties (natural variation in the system) and epistemic uncertainties (variation due to lack of knowledge), with the epistemic factors being represented on the outer loop of the Monte Carlo simulations, and the aleatory on the inner loop. In total, 30 epistemic factors and 80 aleatory factors were combined, needing 72,800 individual EnergyPlus simulation runs. Results are presented as Cumulative Distribution Functions (CDFs); figure 2 shows the outcomes for predicted annual cooling energy. Similar graphs have been created for heating energy use and overheating.

![CDFs for annual cooling energy use](image1.png)

Figure 1: 3-D View of the CIBSE TM36 O2 Reference Office

Figure 2: CDFs for annual cooling energy use
In a separate simulation study, the impact of thermal comfort modelling on the predicted behaviour under climate change has been analyzed. This is a relevant study, as it is known that humans adapt to the thermal conditions, whereas standard comfort control settings in most building simulation tools are static. Results show that overheating risks for the 2020s obtained using a static might increase by a factor 10; whereas overheating risks for that same time horizon obtained with an adaptive model show an increase of less than a factor 2. Further detail of this work can be found in de Wilde and Tian (2010).

Another issue taken into account in the simulation study is intervention. Over the long lifetime of the building, it is likely that building services and building fabric will see multiple upgrades. Three types of intervention scenarios have been investigated: a base-case scenario, where properties of systems and fabric maintain constant over time (a ‘like-for-like’ replacement); case A which represents moderate investment in the building and a relatively slow upgrading of building energy efficiency; and case B which represents more aggressive investments in upgrading the building energy efficiency. For cases A and B, intervention times have been assumed based on literature review; in between interventions systems and fabric properties are again taken to be constant.

A probabilistic simulation of the TM36 O2 Reference office, taking into account a range of uncertainties, can yield the probability of occurrence of indoor air and surface temperatures throughout the building. This can be mapped into the probability ($P_f$) in formula (1). This can then be combined into consequences ($C_f$) to obtain risk, using the same formula. To this end, EnergyPlus results have been linked to a formula that relates said temperatures to a predicted ‘relative work performance’, using work by Fisk and Seppänen (2007). Typical results are depicted in Figure 3. Note that predicted relative work performance is adding a range of assumptions on top of the temperature probability, and that hence the projection of relative work performance is much more coarse than the prediction for temperatures in itself.

![Figure 3: Predicted relative work performance for the TM36 O2 Office](image)
The results for predicted relative work performance demonstrate the limits of using a theoretical reference building. While overall results are interesting, indicating a risk of a reduction of work performance of about 3%, there are issues that the research team would like to discuss with the stakeholders in the building. For instance, is one aggregate relative work performance figure a relevant performance metric, or would an actual facilities manager prefer a higher spatial resolution? Note that overheating effects are more likely to occur on the top floor, and in the southwest-facing rooms/zones of the building. Also, is relative work performance itself a valuable metric for facilities management, or would professionals prefer the original underlying data in terms of temperature series and overheating hours?

The actual existing building is the Roland Levinsky Building, a flagship facility at the authors’ campus. This provides good access to the people involved in the design, engineering, construction and FM processes (client, expert consultants, contractors, estate department) and a wealth of related documents. Furthermore, further information on building details, occupancy patterns etc. can be obtained on-site whenever needed. The building is a multi-purposed facility for use by staff, students and the general public, delivering a home for the Faculty of Arts along with theatres, a café, generic teaching spaces and administration services areas. It has about 13,000 m² of floor space and is nine-storey high, see Figure 4. It comprises a reinforced concrete frame with post-tensioned slabs, long span beams and a steel roof structure. The copper cladding wraps from the two-storey west elevation and forms the complex roofs and eastern facades for the eight-storey elevation. The north and south facades are entirely glazed with low SHGC (solar heat gain coefficient) windows. Mechanical ventilation has been implemented in this building because of the noise and pollution in the city centre. Ventilation is controlled by variable speed fans with a supply air temperature of 19°C. Multiple air handling units allow varying occupancy schedules for different space uses, such as classrooms, offices and theatres. The air-cooled chillers provide cooling water to coils in the air handling units and fan coil units. Gas-fired condensing boilers supply hot water to heating coils, a perimeter trench system and wall-mounted radiators.

Figure 4: Photo of the Roland Levinsky Building at the University of Plymouth campus
The complex geometry of the Roland Levinsky Building was modelled with the OpenStudio (Sketchup) plugin for EnergyPlus. The final building model has 105 zones. Two versions were made regarding services in the model: one with simplified services, sized as per heating demand, and one a detailed HVAC (heating, ventilation and air conditioning) system representing the actual system layout.

The simulation studies for the Roland Levinsky Building employ the recently released UK climate change predictions from UKCP09 (Murphy et al., 2009), which provides probabilistic climate change projections by means of a weather generator. For a given time period and emission scenario, the UKCP09 weather generator will generate 100 time series, each of which includes a 30-year hourly output for baseline and specified future time slice. Finkelstein–Schäfer statistic is used to create one typical weather file from every time series of 30 years in length. This yields 100 typical weather files for a specified time slice and emission scenario. In order to analyse current and future thermal behaviour a series of time horizons and scenarios must be explored; at present this is still computationally expensive and requires 1000 EnergyPlus runs. This would take about 23 days on a regular office PC; hence use has been made of the local computing grid, allowing to run the same computations on different machines in parallel and reducing the computation time to just one weekend, see Figure 5.

Figure 5: University of Plymouth Plymgrid usage statistics.

Initial results are just becoming available. These have been combined to plot cumulative distribution functions for annual heating energy, annual cooling energy and carbon emissions for the baseline period of 1961-1990 and future time horizons for the 2020s, 2050s and 2080s. See figure 6. Simulation results show that, by the 2050s, the mean annual cooling energy will have increased by 135% while the mean annual heating energy will have decreased by 40% relative to the current situation. The annual greenhouse gas emission will increase by about 20%. Work is currently starting to calibrate these initial results with data from the Building Energy Management System.
Overall, the building performance simulation studies (on both the TM36 O2 Reference office and the Roland Levinsky Building) lead to the following findings:

- It is possible to predict future thermal performance of buildings, taking into account a range of uncertainties, using (probabilistic) simulation.
- If so desired one can distinguish between aleatory uncertainty and epistemic uncertainty. However, in the context of actual projects the boundaries between these two become fluid.
- The usefulness of simulation results depends critically on modelling assumptions. For instance, choices made regarding thermal comfort (static or adaptive model) can have an impact of up to a factor three on predicted energy use.
- The new climate predictions of UKCP09 can be used in building simulation, but are computationally expensive. Strangely, UKCP09 does not contain predictions regarding wind, with the report mentioning that these would have too large an uncertainty range. This might be relatively unimportant for some buildings, but can be a crucial factor for naturally ventilated buildings, or buildings where convective heat exchange is dominant (e.g. U-value of glazing).
- There are limits to what can be learned from studying a theoretical reference office like TM36 O2, as this does not allow the essential feedback of building stakeholders to computational results, and does not include an operational facilities management context. At the same time, studying actual buildings brings in so much additional detail that selection of what is considered to relevant and what can be simplified turns dominant.

4. Expert panel workshops

Results from the building simulation studies have been discussed with colleagues from practice and academia by means of a series of expert panel workshops. In these workshops the simulation research
was presented, and feedback solicited from the workshop participants. Three workshops have been held thus far:

WS1: Invited lecture at Georgia Institute of Technology, College of Architecture, in the local Building Technology Seminar Series (Atlanta, USA, 30/10/2009; 20 participants)

The workshops have yielded the important feedback on the research, which is centred on two areas: refining the simulation and examining the ‘soft’ factors, with a purpose to improve future design and FM decision practice in response to climate change.

4.1 Refining the simulation

A number of comments were obtained regarding refining the simulation. Firstly, simple, pre-defined building intervention scenarios are not realistic. In real facilities management, the performance of a system will deteriorate, until a point is reached where the decision is made to replace that system. To represent this in the simulation, a coupling between predicted performance and interventions is needed. Secondly, even a building is designed without any climate change concerns being included in the client’s brief, the CIBSE Design Guide might still provide a set of background requirements that any building in the UK will have to meet. Thirdly, although the study of the Roland Levinsky Building is interesting, a careful approach is needed to validate probabilistic simulation results against actual meter readings, for instance, from the Building Energy Management Systems (BEMS).

4.2 Examining ‘soft’ factors

Several ‘soft’ factors were also identified, which, although appearing difficult to be modelled in the simulation for the moment, were considered important to design and FM decision practice in relation to climate change. Firstly, the simulation engaged in this research was based on the use of gas-fired boilers as the base case, whilst it should not be unusual to expect a shift in technology over the lifetime of the building. For instance, the current gas-fired boiler might be replaced by a ground-source heat pump system, which might actually be likely to happen given the increasing take-up of alternative heating and cooling technologies for buildings in the UK, e.g. ground source heat pumps (Omer, 2008) and air source heat pumps (Jenkins et al., 2008). Also, it appears that electricity-driven technologies will increasingly be preferred to gas options in buildings, given the trend of decreasing carbon intensity of the grid. Therefore, potential technology development and diffusion in building seems to impose an uncertainty on the modelling approach. Secondly, the functional adaptability of the building, i.e. potential use changes during its lifetime, was not considered in the simulation. Also, the client’s desire on and maintenance strategy for the building were not considered. From an estates point of view, building management is asset management, and is related to reserving funds for maintenance and interventions. This type of research, which explores when to intervene, seems very informative for that type of decisions. Thirdly, an extension of ‘operating energy’ to ‘relative work performance’ is relevant when taking a monetary view of decisions. An apparently small reduction in
work performance of about 3% can equal the total cost of energy use per year when translated into investments.

### 4.3 Recommendations

Amalgamating the comments/feedback on the two areas suggests a balanced strategy for managing climate change risk for future buildings in relation to design and FM decision-making. On the one hand, attempting to consider too many uncertainties on the input side would yield simulation results that provide less useful information. On the other hand, the important ‘soft’ factors should be taken into account, with the simulation results, for enabling more effective design and FM decision practice (Figure 7).

![Diagram of climate change risk management for building design & FM decision](image)

**Figure 7**: Model of climate change risk management for building design & FM decision

Both the simulation results and considerations for the ‘soft’ factors should be taken into account by the client and their professional advisers and FM managers for managing the climate change risk of the building. Recommendations to be made drawing on both ‘hard’ and ‘soft’ inputs would enable the development of improved design and FM decision processes. Apparently, a range of building stakeholders including the client, their professional advisers, FM managers, occupants and the public would need to be engaged. The management of climate change risk of the building would also need to involve a continuous review of the statutory, regulatory and technological context of building design and management.
5. Conclusions and remarks

This paper, reporting on a combination of the building performance simulation studies and expert panel workshops, has demonstrated that simulation can play an important role in managing buildings that are subject to a changing climate. However, computational studies need to be grounded in a real-life context to be of use. The development of relevant models needs to involve the stakeholders to ensure sufficient resolution on relevant details, covering non-trivial issues like uncertainties in renovation/intervention activities, changing heat loads and user profiles, thermal comfort control assumptions, and system degradation. A general probabilistic approach will just yield that many input uncertainties lead to an uncertain future performance. The way forward in this field of research is a series of case studies that focus on actual buildings, which allows to consult stakeholders and to frame the relevant facilities management decisions in their real-life context, which can include non-thermal ('soft') factors.

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Climate Change: An Opportunity for Progress?

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Abstract

The likelihood of a global climate change is now acknowledged by the scientific community. Recent events may be considered as signs of future situations. But it is too early to think of a deep revision of presently used construction rules. Based on the analysis of the consequences of these events, and on the results of climatic changes simulation, this paper presents the idea that the construction community is likely to learn a lot to know how better use existing rules. In this way, the threat of a global climate change will benefit the newly built constructions as more attention will focus on essential design and realization points. Before becoming a severe threat for the future, we consider climate change as a major opportunity to do better today. Since civil engineering structures and buildings are major parts of our built environment, it is logical to wonder how climate change could impact it in terms of security, use comfort or maintenance costs for example. Two general strategies are generally developed in order to cope with climate change issues: mitigation and adaptation. But is it possible to move on from 'coping with climate change' to consider it as an opportunity for progress? This article analyses potential climate change impacts on buildings, as part of the built environment, both studying existing and new constructions. These impacts range from general actions (wind, temperature) being different from today, to better integration of sustainable development issues in design. It is worth to wonder if such changes could lead to change building traditions as well, for example in modifying the present distribution of building techniques. Gathering all these items in a single analysis leads to focus on potential axes. First, it enables to compare present regulations and standards with future climate evolutions so as to estimate the security margin available. Then, the article explores some ways to answer new challenges brought by climate change, like improving security level and comfort in existing buildings or ensuring a good practice of today design code's satisfying requirements in new structures. Promoting building habits that are compatible with future climate situation is another meaningful axe.

Keywords: climate change impacts, adaptation measures, building
1. Introduction

The description of ancient buildings and of the first cities by historians shows that most of the technical and symbolic features of these early constructions were very similar to that of contemporary buildings. This is for instance obvious for building functions such as the protection against wind, rain, heat, cold… Walls, roofs, openings are universal solutions that ensure these functions. Nevertheless, the detailed solutions imagined and developed by human groups over time and space are very diverse according to local climate, culture and resources. This fact becomes evident when travelling in different countries.

Vernacular buildings were for long built using techniques developed pragmatically through trials and errors processes. The strong development of sciences since the XVIIIth century allowed a better understanding of building physics. This knowledge, together with the unprecedented industrial development that started during the XIXth century brought innovative ways to ensure building functions: new material such as steel, reinforced concrete, prestressed concrete, plaster boards, float glass… The conjunction of all these innovations together with the availability of cheap energy resources (mainly natural fossil fuels such as oil, gas, coal…) dramatically changed the building industry during the XXth century. Demands for all-season indoor comfort requiring both heating and cooling equipments have for instance been constantly rising in many part of the world.

The most industrialised countries first used these technologies to develop comfortable buildings. There are no reasons why other countries would not demand for similar living conditions. A major issue in such a perspective is that these convenient and comfortable buildings built during the last decades consume an enormous amount of energy. As it now becomes clear that the recent period of low cost energy may soon (at the human scale of time: within decades or maybe within one or two centuries) come to an end whilst reserves tend to decrease, this perspective may clearly not be sustainable. This fact, together with the exponential growth of the world population is one of the factors at the origin of the so-called “sustainable development”.

In response to these growing concerns, both adaptation and mitigation strategies are being developed simultaneously. While the mitigation concept, i.e. the reduction of greenhouse gases (GHG) emissions, is easily understood, the concept of adaptation is more difficult to explain. In addition to the reinforcement of thermal insulation, the pallet of mitigation measures encompasses for instance bioclimatic design closely linked to local climate, efficient equipments with adapted controls, choice of products with low energy content, occupants’ behaviour including careful building maintenance. Mitigation measures refer to short term and measurable expected benefits (for instance a measurable energy consumption decrease can be observed during years following the reinforcement of a building thermal insulation).

Adaptation concerns all the measures that can be taken to limit the impacts of a new climatic context. Adaptation directly refers to the concepts of vulnerability and resilience. It aims at anticipating local climate change impacts on the built environment. Adaptation refers to both immediate decisions (I am cold, I put on a pull-over) and long term effects (long term meaning for the next generations) for which costs of decisions have to be paid now. The first example concerning the immediate decision to
put on a pull-over shows some similarities with mitigation measures: immediate (or short term) benefits are expected from a better insulation. We name it spontaneous adaptation. The second example refers to decisions in a rather uncertain context: we name it planned adaptation. In this latter case, sound questions have to be raised as the expected benefits are both on the long term and uncertain: Can’t resources used for adaptation be spent for something else with more immediate benefits? How can the consequences of not taking adaptation measures be assessed? The concept of mitigation and adaptation are intrinsically linked as illustrated on figure 1.

Figure 1: link of construction with climate change: mitigation – adaptation

Facing such a perspective, what can the construction professionals do? Is the traditional construction process unsuitable and why? How important is the shift towards new practices that may appear to be necessary to build better adapted buildings? How can a millenary activity change over a very short period of time? This article proposes a framework to address these questions and prepare answers for the mid-long term horizon.

2. Buildings and their climatic environment

In order to define adaptation measures, we need to precise what is expected from a building as well as to describe the way’s climatic parameters may impact buildings. These objectives are achieved respectively through two frameworks: 1) building functions and 2) a representation of the links between climatic parameters and building parts.

2.1 Buildings’ functions

According to Gobin (1997), table 1 presents a set of generic functions that are expected from buildings. This description shows how these functions are closely linked together. These links
underline the systemic character of a building. The art and skills of designers and builders is to find for each project an economical equilibrium between these functions that meets expectations and budget constraints of the client. The balance between functions will obviously be different for a school building, a dwelling or an office building. This analysis should also ideally take into account the exploitation phase including maintenance. The origin of buildings defects indeed often comes from a loose understanding of the fact that a building is a system which must remain in equilibrium. Imprecise specification, loose design, incorrect implementation, inappropriate (or inexistent) maintenance are examples of defects origins. The life cycle of a building is intrinsically long: decades not to say centuries and the codified rules are rather recent (structural regulations were introduced at the end of the XIXth century and energy regulation was inexistent before the first 1973 oil shock).

Table 1: Functions of a building

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Provide adapted spaces to carry out activities</td>
<td>This is the service provided by the building that allows users to have at their disposal suitable spaces as regard to activities which are to be carried out.</td>
</tr>
<tr>
<td>F2</td>
<td>Protect occupants and goods</td>
<td>This is the service provided by the building that protects users and goods against natural (climatic, seismic ...), accidental (industrial gas emission, fire ...) or voluntary (aggression, theft ...) events.</td>
</tr>
<tr>
<td>F3</td>
<td>Allow access and use of goods and tools</td>
<td>This is the service provided by the building that allows occupants to use tools required by their activities and to take advantage of their goods.</td>
</tr>
<tr>
<td>F4</td>
<td>Provide an adapted ambiance</td>
<td>This is the service provided by the building that allows the user to adapt indoor ambiance according to outdoor ambiance.</td>
</tr>
<tr>
<td>F5</td>
<td>Control relations between occupants indoor/outdoor</td>
<td>This is the service provided by the building that allows the occupants to control (choose, favour, avoid ...) their relations with others as well as with the environment.</td>
</tr>
<tr>
<td>F6</td>
<td>Environmental “friendship”</td>
<td>This is the service provided by the building that allows occupants to live without impacting the environment.</td>
</tr>
<tr>
<td>F7</td>
<td>Semiotics</td>
<td>This is the service provided by the building that reflects the quality of life of the occupants and creates the appropriation.</td>
</tr>
</tbody>
</table>
2.2 Describing impacts of climatic parameters

The variability of climatic parameters (wind, temperature ...) has for long been acknowledged. First regulations considered average parameters values whilst more recent regulations such as Eurocodes introduce probabilistic approaches. When considering potential new climate schemes that may result from climate change, the question of the variability of the climatic parameters over the life cycle period of the building has to be considered differently. Some functions that were originally well calibrated (according to applicable regulations) when the building was erected may become more difficult (or easier) to ensure according to changes of climatic parameters of the original range of variation. For example, temperatures higher than the design values may drive to a lack of comfort and extra energy consumption for cooling. The adequacy of the building design and construction should be appreciated on the long term an d adaptation to a new climatic context should be considered. Interactions between a building and its environment then need to be described.

Figure 2: description of interactions between building generic parts and climatic parameters

Figure 2 is an attempt to illustrate such relations. It describes buildings as a system that interacts with its environment. The building is represented by four generic parts: 1) Structure: walls, frames, 2) Envelope: openings, roof, 3) Networks: water, electricity, waves, sewer, 4) Equipments: appliances, partition walls, furniture... These four parts are linked together as well as they are related to two surrounding medias: 5) Soil, which supports building through foundations and includes underground networks 6) Air, which surrounds the building and which flows through indoor spaces where it heated/cooled/conditioned.
The link between generic parts and media can be direct (thrust of wind on the structure and envelope) or in direct (outdoor temperature and rainfall impact soil characteristics that influence stresses on structures or buried networks). This technical system is embedded in a more global item (not represented) which corresponds to the values allocated to the building: usage, money, symbols, images … Though this description also comprises seven items (including the latter mentioned), there is no one-to-one correspondence between them and the seven generic functions of Table 1. The purpose of generic functions is to allow a common understanding of what a building is. The description of Figure 2 is needed to have a systematic approach of climate impacts and to imagine adaptation measures.

3. An example: clay soil swelling and shrinking

Clay soil drying shrinking and rehydration swelling is known to have very costly consequences on building structures in many countries. In France, it is for instance the second largest share of total insurance compensation after flood (CCR (2009)). This chapter deals with this natural hazard which is very sensitive to climatic conditions.

3.1 Description of phenomenon

The phenomenon of clay soil drying shrinking and rehydration swelling has been observed for long. It is rather well described and the cost of repair is known to be very high in all concerned countries. It hits mainly buildings with shallow foundations. Cracks and structure failures are the most common consequences. To avoid them, technical solutions principles are rather well known but the diffusion of these good practices has to be supported by a constant effort of information and training. In all these countries, a set of measures were adopted ranging from recommendations to regulations and controls (concerning design, soil characteristics determination and skills of stakeholders), so as to promote less vulnerable construction and to reduce potential repairation costs. (Salagnac, (2009))

According to a shared knowledge on the laws of physics, all these measures point out common technical issues such as:

- the determination of appropriate foundation depth according to the local clay soil characteristics,

- the design and realisation of foundations as a function of the potential soil subsidence,

- the care to be taken about the choice of trees (that may suck a significant quantity of water depending on essence) to be planted at a minimum distance of building foundations, and other measures on the surrounding environment.

More interestingly, countries differ in the implementation of these rules. Depending, among other parameters, on the construction defect insurance scheme, the organization of stakeholders shows a great diversity. The kind of control (before or after the construction, systematic or not, just in case of
defect …) indicates the existence of diverse approach of natural risk. These diverse organisations reflect cultural issues and, even if one system was definitely better than all other ones, the transfer to other countries would probably meet some difficulties because it would introduce important changes in the current (tradition-based) construction process. This example illustrates that we probably do not miss technical solutions to cope with natural hazards but that we have to drastically improve their implementation.

3.2 Impacts on generic parts and consequences on building functions

Using both the functions of table 1 and the generic parts of figure 2 it is possible to highlight a relation between the impacts of ground movements due to clay soil subsidence and the consequences for occupants. Table 2 is limited to functions which are affected as a consequence of generic parts failure mode. Functions which are not affected are not mentioned. This qualitative analysis has to be further developed in order to assess economical consequences of failure modes. When this is available, it is then possible to design generic parts (in relation with media, i.e. clay soil) so as to limit the vulnerability of building erected in a clay soil subsidence-prone area.

Table 2: Failure modes of buildings generic parts and consequences on functions (clay soil subsidence)

<table>
<thead>
<tr>
<th>Generic part</th>
<th>Impacts (failure modes)</th>
<th>Function</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Floor cracks</td>
<td>F1</td>
<td>Difference of floor level (hazard for occupants)</td>
</tr>
<tr>
<td></td>
<td>Wall cracks</td>
<td>F2</td>
<td>Loss of water tightness, loss of stability</td>
</tr>
<tr>
<td></td>
<td>Floor cracks</td>
<td>F3</td>
<td>Difference of floor level (hazard for occupants)</td>
</tr>
<tr>
<td></td>
<td>Wall cracks</td>
<td>F7</td>
<td>Loss of image, loss of value</td>
</tr>
<tr>
<td>Envelope</td>
<td>Difficulty to open windows and doors</td>
<td>F1</td>
<td>Loss of serviceability</td>
</tr>
<tr>
<td></td>
<td>Cracks between walls and windows/doors</td>
<td>F2</td>
<td>Loss of water tightness</td>
</tr>
<tr>
<td></td>
<td>Cracks between walls and windows/doors</td>
<td>F4</td>
<td>Loss of performances (thermal, acoustics)</td>
</tr>
<tr>
<td></td>
<td>Cracks between walls and windows/doors</td>
<td>F7</td>
<td>Loss of image, loss of value</td>
</tr>
<tr>
<td>Equipments</td>
<td>Cracks in chimneys (indirect impact)</td>
<td>F4</td>
<td>Appliance malfunctioning</td>
</tr>
<tr>
<td>Networks</td>
<td>Pressurised water pipes breakage</td>
<td>F2</td>
<td>Flooding, risk of explosion</td>
</tr>
<tr>
<td></td>
<td>Gas pipe squeezing or breakage</td>
<td>F2</td>
<td>Flooding, risk of explosion</td>
</tr>
<tr>
<td></td>
<td>Tubes squeezing</td>
<td>F3</td>
<td>Loss of appliances serviceability</td>
</tr>
<tr>
<td></td>
<td>Pipes breakage or tubes squeezing</td>
<td>F4</td>
<td>Appliance malfunctioning</td>
</tr>
<tr>
<td></td>
<td>Used water pipes breakage</td>
<td>F6</td>
<td>Pollution by waste water</td>
</tr>
</tbody>
</table>
3.3 Influence of climatic parameters

Figure 3 shows the evolution of compensated insurance claims, with in the context of the French natural disaster compensation scheme (known as CAT-NAT scheme), for clay soil subsidence events over the period 1989-2003 in France (CCR (2009), Plat (2009)). In 2003, the number of claims reached about five times the average annual number of claims on the period 1989-2002. The 2003 summer heat wave undoubtedly fuelled such a peak in claim numbers among other consequences for the built environment (Salagnac (2006)). The clay soil subsidence phenomenon does not only depend on external air temperature. Other parameters such as precipitations during the months before the heat wave event also have a great influence. For years with successive heat-waves, the consequences will probably be more important than for an isolated heat-wave period. Knowledge has still to be produced to better understand the phenomenon in details so as to be able to foresee conditions that would potentially impact building structures. Nevertheless, the observation made in 2003 and the very likely increase in frequency of such heat waves during this century (IPCC (2007)) must raise the awareness of builders, building owners and insurers regarding the potentially more important consequences of these climatic events. This is the reason why adaptation has to be considered.

![Figure 3: evolution of compensated clay soil subsidence claims in France (Plat (2009))](image)

3.4 Adaptation measures: definition and economical perspectives

Ideally, a strict respect of design rules mentioned in 3.1 is likely to strongly limit the impacts of clay soil drying shrinking and rehydration swelling on building structures. The question is that the majority of the potentially impacted buildings are individual houses. These buildings are generally not very sophisticated constructions and less care is taken for their design and erection than for any other building with a higher (economic, symbolic) value. An ongoing experiment could highlight this assertion. It consists of a masonry individual house erected on jacks on the floor of an experimental hall (Plat (2009)). This building is built with a strict respect of the masonry structural code and the consequences of the withdrawal of jacks (simulating the shrinking of clay soil) are said not to have any consequences up to now. Anyhow, construction site is not an experimental hall and these encouraging perspectives must be extended in order to develop construction techniques and processes that are site-consistent. Extra knowledge and exchange of experiences have to be promoted in order to assess results, define suitable conditions for the implementation of these good practices such as stiffened slab reinforcements (figure 4). In this way, the perspective of adaptation to climate change
impacts may be a good opportunity for progress in the building construction sector: assessment of the robustness of existing rules, revision of design rules, improvement of quality insurance management process (define which, where and when vulnerable building parts have to be controlled), development of technical and organizational innovation.

Figure 4: site view of stiffened slab reinforcements (courtesy of J-L Briaud, Texas A&M University)

All these technical and organisation considerations have to be developed with regards to economical issues. Changing the habits of designers and of contractors is not economically neutral. A first guess in the French context was made with the following set of assumptions: constant rate of growth of construction of masonry individual houses in subsidence prone areas equal to the observed rate over last decade, no modification of the natural disaster compensation scheme but introduction of several options among which stiffened slab reinforcements and deeper foundations.

The cost (introduction of new techniques, reinforced control) and benefits (expected decrease of structural failures) analysis according to the present average compensation level (about 12 000 Euros per house) was not clearly encouraging for a strong improvement of the present situation (Plat (2009)). The results did not show a significant decrease of the global cost over the decades to come. This result may not be completely surprising within the particular insurance context of the French CAT-NAT scheme as the consequences of events are shared by all insured even when they have no exposition to the subsidence hazard (CCR (2009)). There is no strong incentive in this context for isolated actors to progress. This first attempt to evaluate the cost of adaptation measures calls for further developments in research. In particular, comparisons between different insurance contexts have to be carried out. Hypothesis on the evolution of the insurance context should also be explored.

4. Conclusions

Adaptation is acknowledged to be a must in the perspective of climate change. The question is how to address this issue from a practical point of view. We have presented a general framework to qualitatively and quantitatively assess the impacts of climatic hazards. The use of this
framework was presented more in detail for a particular hazard: clay soil drying shrinking and rehydration swelling. We only insisted on the shrinking during hot periods but swelling also has structural effects. Nevertheless the choice of this phenomenon is quite interesting as it is rather well documented and because of the high insurance compensation costs.

This framework looks to be promising to analyse other climatic hazards (flood, wind, urban heat island …) by allowing open possibilities to establish links between climatic parameters variation, behaviour of generic building parts and impacts on building functions. Nevertheless, the difficulty to assess these parameters in selected climatic scenarios as well as to select climatic scenarios at a local level is real.

We have concluded from the chosen example that thinking about adaptation was probably a good opportunity for progress in the construction sector as questions addressing the vulnerability of the building stock (both existing and future buildings) have to be addressed again in a new perspective. This is indeed not a new task to assess how vulnerable to climatic parameters a building is. This is not a new task to define and codify technical rules so as to promote economical solutions. But the interesting thing with adaptation is that these already processed tasks have to be worked out again to:

- consider both adaptation and mitigation issues,
- address non technical issues such as insurance, competences, rules design and dissemination, control,
- improve economical approaches.

This is a very challenging perspective and we hope that it will be shared by the construction research and professional communities.

Acknowledgement

This paper refers to reflexions carried out within the frame of the cross ministerial group in charge of preparing the French national adaptation plan to climate change in 2011. It reflects exchanges with experts (building, insurance, research …) met in this group.

References

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Climate Change and Urban Planning

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Abstract

The aim of the study is to promote adaptation to and mitigation of climate change in urban planning and, thereby, to reduce damages caused by floods and storms as well as to reduce greenhouse gas emissions. The research was based on ongoing planning processes in six study locations in Finland. The study analyses plans at different levels: regional, master and detailed plans. Plans were considered on the basis of local climate conditions and of the microclimate they will form. Mitigation of climate change was considered by assessing greenhouse gas emissions from realizing the plans. The bases for analyses are estimations about essential impacts of climate change in the case localities. Predictions of climate change with regards to extremes and certain average changes in the next hundred years were made for all the study localities. The predicted variables concerned temperature, wind speed, precipitation, snow cover and sea ice cover. Changes in many variables are significant and differences between localities are great. Near shorelines, changes of sea level and flood risk areas were also estimated. With regards to adaptation to climate change in plans at general levels, important issues are mapping of flood risk areas and avoiding location of functions in such areas. Wind conditions and increasing precipitation form challenges to detailed planning. Near shore areas, sea level rise and splash of waves, as the sea will be open longer, form special challenges. Regarding climate change mitigation, advantageous areas are those which are located favourably with respect to traffic conditions, especially those having possibilities to walk, bicycle and use public transportation and which can use district heating or use renewables in separate heating. The research shows that mitigation of and adaptation to climate change can be considered at the same time. Results of the project are recommendations of practical procedures and means for taking climate change into account in urban planning and impact assessment. Control of and adaptation to climate change should be an established practice in urban planning.

Keywords: climate change, mitigation of climate change, adaptation to climate change, urban planning, greenhouse gas emissions
1. Introduction

Control of climate change is a major global and national goal. The aim of the study presented in this paper is to promote adaptation to and mitigation of climate change in urban planning and, thereby, to reduce damages caused by floods and storms as well as to reduce greenhouse gas emissions. Challenges of climate change for urban planning are that urban form should be developed so that all processes of production and use of structures as well as transportation product as little as possible greenhouse gas emissions which promote climate change, and, on the other hand, so that climate change causes for built environment and people as little as possible harmful effects and that the possible positive effects could be utilized.

The study analyses plans at different levels: regional, master and detailed plans. The bases for analyses are estimations about essential impacts of climate change in the case study localities. Plans were considered on the basis of local climate conditions and of the microclimate they will form. Mitigation of climate change was considered by assessing greenhouse gas emissions from realizing the plans. Results of the project are recommendations of practical procedures and means for taking climate change into account in urban planning and impact assessment. (Wahlgren et al 2008, 2008b, Wahlgren 2008)

2. Prediction of climate change

Predictions of climate change with regards to extremes and certain average changes in the next hundred years were made for all the study localities. Predictions were based on new methods developed in VTT: s research project “EXTREMES” (Makkonen 2005, 2006, 2008, 2008b, Makkonen et al 2007, Makkonen and Tikanmäki 2008). Predictions are based on simulation results of the regional atmosphere-ocean climate model RCAO of Rossby Centre, Sweden. Analyses concerning extremes have been made by University of Helsinki and VTT. Simulations were made with boundary conditions of two global models (Hadley Centre and Max Planck Institute) and using two emission scenarios (A2 and B2) by IPCC. Results concerning changes describe mean values of four simulations at counting points near study locations, which respond 50 km x 50 km area in the model. “Present condition” is based on control simulations 1961-1990 (input: measured atmosphere) and “prediction” is based on scenario simulations 2071-2100 (input: IPCC emission scenarios A2 and B2). Extremes or maxima and minima describe on average once in a 50 year period exceeding (or going below) values. (Figure 1)

The predicted variables were average temperature of a year, maximum temperature, minimum temperature, freeze-thaw cycles, average wind speed of a year, maximum wind speed, average precipitation of a year, 6 hours precipitation maximum, 5 days precipitation maximum, 6 hours snow maximum, snow cover maximum, duration of snow cover and duration of sea ice cover (Table 1). Changes in many variables are significant and differences between localities are great. Near shorelines, changes of sea level and flood risk areas were also estimated. (Wahlgren et al 2008)
Figure 1: Prediction of climate change in study locations, simulations by global and regional climate models, average of 4 simulations. Control simulations 1961-1990, input: measured atmosphere. Scenario simulations 2071-2100, input: IPCC emission scenarios A2 and B2. Prediction range 110 years, prediction from today 80 years (Wahlgren et al 2008)

Table 1: Predicted climate change during this century in study locations, Finland. Extremes or maxima and minima describe on average once in a 50 year period exceeding (or going below) values. (Wahlgren et al 2008)

<table>
<thead>
<tr>
<th>Study location</th>
<th>Helsinki</th>
<th>Uusimaa, coast</th>
<th>Uusimaa, inland</th>
<th>Kokkola</th>
<th>Kuopio</th>
<th>Sodankylä</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average temperature of a year °C</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Temperature maximum °C</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Temperature minimum °C</td>
<td>16</td>
<td>16</td>
<td>11</td>
<td>12</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Freeze-thaw cycles %</td>
<td>-40</td>
<td>-40</td>
<td>-30</td>
<td>-25</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Mean wind speed of a year %</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Wind speed maxima %</td>
<td>15</td>
<td>15</td>
<td>5</td>
<td>-5</td>
<td>-10</td>
<td>9</td>
</tr>
<tr>
<td>Precipitation of a year %</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Precipitation maximum 6 h %</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>40</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td>Precipitation maximum 5 d %</td>
<td>15</td>
<td>15</td>
<td>30</td>
<td>55</td>
<td>56</td>
<td>55</td>
</tr>
<tr>
<td>Snow precipitation maximum 6 h %</td>
<td>0</td>
<td>0</td>
<td>-5</td>
<td>30</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Snow maximum %</td>
<td>-50</td>
<td>-55</td>
<td>-50</td>
<td>-35</td>
<td>-37</td>
<td>-3</td>
</tr>
<tr>
<td>Duration of snow cover d</td>
<td>-70</td>
<td>-70</td>
<td>-70</td>
<td>-60</td>
<td>-45</td>
<td>-40</td>
</tr>
<tr>
<td>Duration of ice cover of sea d</td>
<td>-120</td>
<td>-120</td>
<td></td>
<td>-80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Case studies

3.1 Study locations

The research was based on ongoing planning processes. The study areas and plans were the Kalasatama master plan in City of Helsinki, the Vanhansatamanlahti master plan in City of Kokkola, the urban structure alternatives of Uusimaa region, the development plans of Tahko tourist centre in City of Nilsiä, the Town of Islands in City of Kuopio and the new dwelling area of the former race track in Municipality of Sodankylä (Figure 2).

Figure 2: Case study locations in Finland: City of Helsinki, Uusimaa Region, City of Kokkola, City of Kuopio, City of Nilsiä, Municipality of Sodankylä (Map: Google)

3.2 Master plan of “Fish Harbour”, City of Helsinki

Former harbour and industrial areas of “Kalasatama” (“Fish Harbour”) will be changed into a new waterfront city quarter by the year 2025. There will be 15 000 residents, 5 000 – 7 000 apartments and 6 000 – 7 000 jobs. The area has an excellent location in urban structure. (Figure 3)

Micro climate analyses were made of quarter plans of the area. Wind conditions and sea level rise and splash of waves, as sea will be open longer, form challenges to planning. Increase of precipitation makes sizing of drainage important. Wind testing of the plan and certain buildings and a green street experimental construction project are recommended. Plans are prepared for sea level and waves rise with floor level minimum + 3.00 m over present sea level.
Relatively small greenhouse gas emissions are expected from energy use of buildings. Temperature rise and dense building reduce heating energy consumption but increase of wind compensates this impact. Greenhouse gas emissions from transportation are estimated to be very small. Transportation is based on walking, cycling, metro and tram. Energy is produced by efficient combined heat and electricity production. Greenhouse gas emissions are estimated to be total 5.8 t CO2-eq/inhabitant, of which buildings produce 5.3 t CO2-eq/inhabitant and transportation 0.4 t CO2-eq/inhabitant. (Wahlgren et al 2008)

3.3 Master plan of Old Harbour Bay, City of Kokkola

Vanhansatamanlahti (Old Harbour Bay) is being planned to have 2 200 inhabitants and 200 jobs and also leisure cottages in 2030. The area is located nearby the centre of City of Kokkola. City of Kokkola, together with Geological Survey of Finland, has made in ASTRA project (www.astra-project.org) mapping and evaluation of vulnerable targets and activities on the Old Harbour Bay Master plan area. Height models have been used for sea level changes in different sea level rise scenarios. Land uplift, after the Ice Age, is in Kokkola about 8-9 mm/year. In maximum scenario sea level rise is estimated to compensate land uplift in the next 100 years. This research analysis is based on maximum scenario and storm flood of 1.5 meters (Figure 4). Flood risk is aspired to avoid by uplifting land surface and by building regulation. Minimum floor levels recommended in different areas are + 2.20 - + 3.00 m from sea level.

Micro climate analyses were made of the master plan (Figure 5) and some detailed plans of the area. Wind conditions and increased precipitation form challenges to planning. Dense-low building and orientation of buildings and quarters to sun are recommended. Wind protection can be provided by buildings and vegetation.
Figure 4: Sea level in Kokkola in 2100, maximum scenario and 1.5 m storm flood (City of Kokkola, ASTRA-project, Wahlgren et al 2008)

Figure 5: Wind analysis of Old Harbour Bay. 1) Low lying waterfront, vulnerable to winds and storm floods, 2) Storm winds and flying drops on shore, 3) Residential area on made-up ground, 4) Much emissions from transport (Wahlgren et al 2008)

Greenhouse gas emissions after implementing the plan are estimated to be total 0.8 t CO2-eq/inhabitant, of which from energy use of buildings 0.7 t CO2-eq/inhabitant and from transportation 0.1 t CO2-eq/inhabitant. Emissions are very small. Energy is produced by efficient combined heat and electricity production, with renewable bio fuels, and heating and cooling energy from sea, too. Transportation is based on walking and cycling. (Wahlgren et al 2008)
3.4 Structure models of Uusimaa region

In Uusimaa region there were 1.45 million inhabitants in 2005 and the population growth is estimated to be + 300 000 new inhabitants and growth of work places + 130 000 new jobs in 2006-2035. Climate change and impacts of development of Uusimaa region were studied by three alternative urban structure models: Model A: Developing small towns, Model B: Developing railway communication (sub models B0, B1, B2 and B3), and Model C: Continuing urban sprawl (Figure 6). Greenhouse gas emissions from energy use of buildings and from transportation in different alternatives were estimated. Model C produces about 10% more emissions than other models (Figure 7).

Figure 6: Urban structure alternatives in the Uusimaa region. On the left Model A: Developing small towns, in the middle Model B: Developing railway communication, on the right Model C: Continuing urban sprawl (Wahlgren et al 2008)

Figure 7: Greenhouse gas emissions of alternative structure models of Uusimaa region (Wahlgren et al 2008)

Present climate and climate change impacts are different on coast and inland areas. Overall flood risk mapping shows need for detailed analysis in several localities. Integration of urban form and clear
definition of urban and rural areas are favourable both from adaptation and mitigation points of view. Relatively dense building and saving nature and recreation areas as well as agriculture and forest areas is recommended. Good microclimate can be formed by building and vegetation. On coast wind conditions form challenges. There are clear differences in greenhouse gas emissions between models. The best alternative is B1, which locates new dwelling and work places in the central metropolitan area and railway communication is completed with metro network to east and west. The least favourable alternative is C, which continues urban sprawl and dispersed settlement grows. (Wahlgren et al 2008)

### 3.5 Town of Islands, City of Kuopio

City of Kuopio is planning and implementing a new district “Saaristokaupunki”, the “Town of Islands”, which consists of a chain of new neighbourhoods. There will be located 6 000 new houses for approximately 14 000 new inhabitants in the year 2020. A new special street (“Street of Islands”) connects the new district directly to the city centre. It promotes cycling and bus transit and integrates the southern parts of the existing urban area with the Inner City. The street crosses a lake and passes several small islands. Due to the aesthetic landscape, the street has been designed for slow driving. It includes a good path for cyclists and pedestrians. Street of Islands shortens distances considerably. Economic and ecological impacts of town structure alternatives of southern city of Kuopio were studied in 2003 using the EcoBalance model (Halme and Harmaajärvi 2003, Harmaajärvi 2000, Wahlgren 2009) (Figure 8).

![Figure 8: Town structure alternatives in the southern city of Kuopio. Location of new residential areas and amount of new residential floor area. Alternative 1 on the right includes the “Street of Islands”. (Halme & Harmaajärvi 2003, Wahlgren et al 2008)](image)

The study shows that the greenhouse gas emissions of the new “Town of Islands” will be substantially lower as compared with the alternative urban structure without the “Street of Islands”. Town of Islands produces 50 % less emissions from transportation than more distant growth areas. (Figure 9). The same result also concerns other impacts: energy and raw material consumption and other emissions as well as costs (Halme and Harmaajärvi 2003). Flood risk areas are mapped. There are
challenges from wind conditions and significant increase of precipitation. Dense structure and conservation of vegetation where possible are recommended. (Wahlgren et al 2008)

![Diagram of Greenhouse Gas Emissions, City of Islands, Kuopio]

Figure 9: Greenhouse gas emissions of the structure alternatives of Kuopio. The “Street of Islands” shall halve emissions from transportation. (Wahlgren et al 2008)

### 3.6 Development plans of Tahko tourist centre

The Tahko tourist centre in the city of Nilsiä is planned to develop as a growing tourist centre. Development plans to 2030 include 360 000 floor-m² new buildings, 3 100 new free time apartments and hotel rooms, 30 000 new beds, total 1.3 million overnights and total 370 000 visitors. Transportation alternatives between city of Kuopio and Tahko tourist centre were studied: Alt 1: private cars and buses, Alt 2: new railway connection. Greenhouse gas emissions were estimated from energy use of tourist and free time buildings and transportation of tourists. Alternative 2 with railway connection from Kuopio produces about 10 % less emission than alternative 1 with private car and bus traffic. Wind conditions and significant increase of precipitation form challenges for planning. Decreasing of snow should be taken into account when planning downhill skiing structures. (Wahlgren et al 2008)

### 3.7 Detailed plan of new residential area in former race track in Sodankylä

The area is planned to have 600 inhabitants, 21 300 floor-m² dwellings and 600 floor-m² services. The area has central location in urban structure. During the planning phase thorough analyses were made of microclimate, vegetation and ecological impacts which affected the final plan (Harmaajärvi 1998, Kuusmanen 2008, Wahlgren 2009). The area is very good as regards climate change control. There are estimated relatively small emissions from buildings and transportation. Wind conditions and increase of precipitation and snowfall form challenges for planning. Vulnerable vegetation needs careful planning. (Wahlgren et al 2008)
3.8 Important choices

With regards to adaptation to climate change in plans at general levels, important issues are mapping of flood risk areas and avoiding location of functions in such areas. Wind conditions and increasing precipitation form challenges to detailed planning. Good micro climate can be formed by planning of quarters, plots and houses. Near shore areas, sea level rise and splash of waves, as the sea will be open longer, form special challenges.

Regarding climate change mitigation, advantageous areas are those which are located favourably with respect to traffic conditions, especially those having possibilities to walk, bicycle and use public transportation and which can use district heating or use renewables in separate heating. Study areas in Helsinki, Kokkola, Kuopio and Sodankylä are located favourably in the urban structure. The urban structure alternatives in the Uusimaa region make it possible to form an advantageous structure. The prerequisites of forming a railway connection to Tahko are worth defining. Well-defined urban areas make it possible to form continuous nature and recreational areas and ecological corridors and networks. Rural building scatters natural areas. New areas should be located in connection to existing urban structure. Functions should be located near each other and mixing of functions should be promoted instead of differentiating.

4. Ten golden rules for planner

On the grounds of the research results, ten golden rules were formulated to take climate change into account from both mitigation and adaptation points of view (Wahlgren et al 2008):

1. Find out local climate conditions and predictions of their changes, especially extremes.

2. Find out possible flood risk areas. Don't locate building on them, if it is not safe and reasonable. Define lowest safe building heights.

3. Complete existing urban form. Don't locate new areas detached from existing structure. Avoid formation of new dispersed settlement.

4. Plan building areas and green areas and networks at the same time.

5. Form good micro climate by taking into account especially impacts of windiness.

6. Plan and make sure rainwater management also when precipitation increases strongly. Reduce surface water runoff to water system.

7. Form areas with combinations of row houses, low rise houses and blocks of flats rather than areas with loose big detached houses. Aspire to relatively dense structure. Promote district heating and use of renewable energy sources.
8. Find out prerequisites for public transport. Form area or structure so that it supports development of public transport. Form good walking and cycling environment.

9. Locate different functions near each other. Mix functions, don't separate.

10. Assess impacts on greenhouse gas emissions, choose best alternatives and solutions. Take into account also other views of sustainable development.

5. Discussion and conclusions

Control of and adaptation to climate change should be an established practice in urban planning. The research shows that mitigation of and adaptation to climate change can be considered at the same time. There were no conflicts between these targets in the study areas. Prediction of climate change impacts in different localities seems to be reasonable because of the differences. The report introduces planning directions and recommendations for taking climate and its changes into account in spatial planning and building on different planning levels. “The golden rules for planner” emphasize local conditions, determining flood risk areas, completing of urban form and avoiding urban sprawl, forming good microclimate, control of storm water, relatively compact structure, district heating and renewable energy sources, prerequisites of public transport, walking and cycling, mixing functions and impact assessment. Measures for climate change adaptation and mitigation in urban planning are often also favourable as regards other ecological, economic and social impacts, and they can promote sustainable development.

Accelerating climate change demands effective means to provide for. Reducing greenhouse gas emissions will be more important as international commitments will be tighten. Thus every action to reduce emissions is important. Mitigation and adaptation activities support each other in affecting impacts of climate change.

Acknowledgement

The author wishes to thank co-researchers Dr Kimmo Kuismanen and Dr Lasse Makkonen.

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Climate Change Mitigation, Adaptation and Water Management in Cities

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Abstract

Adaptation and mitigation appear, on the surface, to be very different in terms of time scale of implementation and effects, actors and types of measures. But can they be combined or neatly dovetailed? This paper identifies a number of measures achieving synergies between mitigation and adaptation in cities. The analysis to arrive at these measures has been done at three levels: building, district and city, starting from a comprehensive description of functionalities each of these levels fulfills. The functional description has been confronted with stresses resulting from climate change (more heat, more peaks in precipitation, sometimes more drought), with the need to save energy and use renewable energy sources, and with considerations on closing water cycles. This resulted in a comprehensive, though general, description of possible measures in buildings, on district level and for the city as a whole. Measures were consequently analyzed for possible linkages between the levels, for synergies and for possible conflicts and side-effects. General conclusions: 1) a considerable part of urban functions will be confronted with the impacts of climate change; 2) considering the time horizon in investments in buildings and urban infrastructure it is now time to consider climate change adaptation; 3) most synergies in buildings are linked with rising temperatures and mitigation measures; 4) most synergies on the district level link water stress and mitigation. A number of measures have been identified with high potential for further research, such as adjustable climate screens in the building shell, energy buffers, building materials, flexible design of the inner space of buildings.

Keywords: climate change, urban planning, adaptation, mitigation, complex systems.
1. Introduction

With over 60% of the land area below sea-level, the Netherlands is particularly vulnerable to the impact of climate change on the water system. Not only sea level rise but also increased river flows threaten the Dutch population in the delta of the rivers Rhine and Meuse. The Dutch research and policy development on adaptation to climate change has so far mainly been concerned with water management. Since a few years the impact of climate change in cities is increasingly recognized (e.g. VROM, 2008). Cities are generally vulnerable to climate change because of the high population density and high economic values (living quarters, business, industry etc) in those areas. Particularly in the Netherlands with many large cities in a relatively low and seaward location, vulnerabilities are high. Temperature rise, flooding risks, increase of extreme weather conditions and longer periods of drought will influence the social, ecological and economic systems of cities. Local adaptation measures are required in order to prevent or reduce negative effects at present and particularly in the future. Decisions in the short term are required, not only to be well prepared in time, but also because a number of adaptation measures are an integral part of e.g. infrastructural works, buildings and urban configuration, that have a long lifecycle or construction period. In other words: the cities we are building now should be able to function under a changing and variable climate for the next 100 years.

Developing adaptation strategies does not imply that the efforts for reducing climate change (mitigation) are no longer needed. Cities play a crucial role in the reduction of climate change due to their high contribution to global greenhouse gas emissions (approximately 78% according to Stern, 2006). Mitigation and adaptation are both crucial in order to maintain safe, liveable and healthy cities, and need to be incorporated in sustainable urban development. As these measures are often interrelated and may reinforce each other, mitigation and adaptation should not be considered separately, but studied and possibly implemented in integrated climate plans (McEvoy et al., 2006).

2. Climate change in Dutch cities and its impacts

Projections of climate change are mostly made by using world climate models. For projecting future emissions of greenhouse gases these models use a range of scenarios that are known as the IPCC SRES scenarios. These reference scenarios reflect a wide spectrum of possible futures with respect to population growth and economic development (IPCC, 2000). They do not include (very stringent) climate policies, however. For the Netherlands the outcomes of world climate models, and thus the range of possible futures as reflected in the IPCC scenario’s, have been leading for designing the national climate scenarios (Van Hurk et al, 2006). Recently more regional and temporal detail has been provided by Klein Tank and Lenderink (2009). Projections on the level of detail of cities are, however, still to be developed.

The four national climate scenarios that have been developed by the National Meteorological Service combine the range of outcomes of the global scenarios in a regional climate model and focus on the variability in climate outcomes. The scenarios consequently differ on two main variables: temperature increase and direction of circulation.
The so called G-scenarios are based on a worldwide average temperature increase of 1°C in 2050 compared to 1990, while the W scenarios are based on an increase of 2°C. The G and W scenarios assume an unchanged circulation pattern, while the G+ and W+ scenarios, on the other hand, assume a changed circulation pattern leading to warmer and wetter winters because of more western winds and warmer and dryer summers as a result of a prevailing eastern circulation (see Table 1).

Table 1: KNMI06 climate change scenarios for 2050 relative to 1990

<table>
<thead>
<tr>
<th></th>
<th>G</th>
<th>G+</th>
<th>W</th>
<th>W+</th>
</tr>
</thead>
<tbody>
<tr>
<td>World average temperature rise</td>
<td>+1°C</td>
<td>+1°C</td>
<td>+2°C</td>
<td>+2°C</td>
</tr>
<tr>
<td>Change in circulation patterns</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Yearly averages</td>
<td>mean temperature (K)</td>
<td>+0.9</td>
<td>+1.2</td>
<td>+1.8</td>
</tr>
<tr>
<td></td>
<td>mean precipitation (%)</td>
<td>+3.2</td>
<td>-1.1</td>
<td>+6.4</td>
</tr>
<tr>
<td></td>
<td>maximum daily mean wind speed (%)</td>
<td>+0</td>
<td>+2</td>
<td>+1</td>
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<tr>
<td></td>
<td>potentiële evaporation (%)</td>
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<td>+5</td>
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<td></td>
<td>Rivierdischarge Rhine (%)</td>
<td>+3</td>
<td>-3</td>
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<td>+1.0</td>
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<td></td>
<td>mean precipitation (%)</td>
<td>+3.6</td>
<td>+7.0</td>
<td>+7.3</td>
</tr>
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<td></td>
<td>wet day (&gt;0.1mm) frequency (%)</td>
<td>+0.1</td>
<td>+0.91</td>
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<td>precipitation on wet day (%)</td>
<td>+3.6</td>
<td>+6.0</td>
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<tr>
<td></td>
<td>10-year return level 10-day precipitation sum (%)</td>
<td>+4</td>
<td>+6</td>
<td>+8</td>
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<tr>
<td></td>
<td>Rivierdischarge Rhine (%)</td>
<td>+7</td>
<td>+6</td>
<td>+14</td>
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<tr>
<td>Summer</td>
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<td>+1.4</td>
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<tr>
<td></td>
<td>mean precipitation (%)</td>
<td>+3</td>
<td>-10</td>
<td>+6</td>
</tr>
<tr>
<td></td>
<td>wet day (&gt;0.1mm) frequency (%)</td>
<td>+2</td>
<td>-10</td>
<td>+3</td>
</tr>
<tr>
<td></td>
<td>10-year return level 10-day precipitation sum (%)</td>
<td>+13</td>
<td>+5</td>
<td>+27</td>
</tr>
<tr>
<td></td>
<td>potentiële evaporation (%)</td>
<td>+3.4</td>
<td>+7.6</td>
<td>+6.8</td>
</tr>
<tr>
<td></td>
<td>Rivierdischarge Rhine (%)</td>
<td>0</td>
<td>-12</td>
<td>0</td>
</tr>
<tr>
<td>Sea level</td>
<td>rise (cm)</td>
<td>15-25</td>
<td>15-25</td>
<td>20-35</td>
</tr>
</tbody>
</table>

Source: Van Hurk et al., 2006.

In summary we can say (all figures 2050 compared to 1990):
Temperate winters and warm summers will occur more frequently. The temperature increase will vary from 0.9 to 2.3°C in winter and between 0.9 to 2.8°C in summer. In 2050 the temperature in Dutch cities will resemble that of cities in central and southern France nowadays.

Winters will become wetter on average, with precipitation going up between 4 and 14 percent. Also the peaks in extreme precipitation will be higher.

The intensity of extreme rainfall in summer increases, but the number of rainy days decreases. On average summer precipitation increases by 3 to 6 percent assuming unchanged circulation. It decreases, however, with 10 to 19 percent with more eastern circulation.

The calculated changes in wind are small compared to the natural variability.

Sea level continues to rise, varying from 15 to 35 cm until 2050.

The projected temperature increases will intensify the urban heat island effect, which has hardly been investigated in the Netherlands so far. Apart from a measuring campaign in the summer of 2009 in Rotterdam, of which the results have not been published yet, the only measurements documenting the urban heat island effect date back to 1970-1971. For the city of Utrecht the average temperature difference between the city centre and the rural surroundings was 1.9°C in winter and 2.7°C in summer (Conrads, 1975, cited in Rahola, 2009). A first investigation of the energy balance of the city of Rotterdam suggests a potential urban heat island effect up to 7 °C (Van Harmelen et al., 2008). As yet, the impact of climate change on the characteristics of the urban heat island is unknown (Rahola et al., 2009).

The changes in climate variables summarised above will undoubtedly influence the lifestyle of Dutch citizens in the coming decades. As the changes are relatively limited and will be noticed only gradually, natural adaptation will be sufficient to cope with many of the impacts. However for several impacts of climate change, planned adaptation measures in cities could be necessary. In buildings, the main impact of climate change will be temperature increases. This will result in a higher demand for cooling in summer and less need for heating in winter. The durability of building materials may be negatively affected: the combination of higher temperatures and more precipitation affects porous building materials like bricks and concrete (Nijland et al., 2009). Other consequences for buildings relate to constructional safety. Roofs will need more rainwater discharge capacity and/or more roof slope to cope with high precipitation extremes (Steenbergen et al., 2009). On city and city district scale, the first signs of a changing climate will probably become apparent in decreased air quality. Warmer summers will enhance formation of low level ozone and smog. Secondly, the increased amounts of precipitation may challenge available storage capacity in compact urban areas: there is simply not enough space in some cities to stow the water. As a result, streets and basements may be flooded, and sewerage systems may overflow. Salinisation, an increasing salt content of water systems, due to sea level rise together with increased ground water extraction might endanger drinking water supply in Dutch cities (Jonkhof et al.,1980). Heavy precipitation and high water levels will also disturb efficient mobility and logistics. Like in other metropolitan areas, road traffic is very dense in the western part of the Netherlands. Extreme weather conditions already cause heavy traffic
jams, and this will only become worse in and around major cities. Accidents in road and rail transport appear to increase with adverse weather conditions (Koetse and Rietveld, 2009). Smaller impacts are foreseen for the infrastructure: possible impacts are road subsidence, flooding of tunnels, railway expansion, and lower headroom at bridges. In a dry scenario (G+ or W+) inland navigation might be confronted with lower water tables which will mean that ships cannot reach affected city harbours. The best known impact for the health sector is the impact of heat waves (Kirch et al., 2005; Huynen et al, 2008; Rahola et al., 2009). Rising temperatures do not only have a direct influence on health but can also lead to sleep disruption, which in turn, affects health, productivity and learning performance. As mentioned above, heat waves often coincide with periods of summer smog, with high concentrations of ozone on ground level, which can trigger asthma attacks and can aggravate breathing difficulties. At this moment, most of these impacts have not yet been quantified. In order to prioritise and implement adaptation measures, more information and reliable data are needed.

Apart from coping with the impacts of climate change, cities have to deliver their share in reaching the goals of climate mitigation policies. The target of the Dutch energy and climate strategy for 2020 is to reduce greenhouse gas emissions by 30%, to reach a 2% energy efficiency improvement per year and to increase of the share of renewable energy to 20% (VROM, 2007). Implementation measures are underway to realize these targets. For the longer term more stringent reductions in greenhouse gas emissions of up to 80% in 2050 will be necessary (see e.g. IEA, 2008). Adaptation measures that in some way or another can be combined with these mitigation measures have the best chances of being realized, as often the barrier to invest in adaptation will be high, when the only motive is to improve the quality of life in case of a possible change of climate in a far-away future.

3. A reconnaissance study into adaptation-mitigation linkages

This paper discusses the results of a systematic investigation into the synergy between adaptation and mitigation measures in Dutch cities. We have limited ourselves to cities due to the strong internal cohesion between the structures of a city and the processes within a city and the vulnerability of cities for climate change impacts. Moreover, in cities investments in infrastructure and buildings are made with a time horizon of 50 to 100 years, for which design decisions are currently being made. The lack of space in cities forces us to find efficient solutions for issues such as the location of facilities for rainwater discharge and storage, for the generation of renewable energy or for creating cool neighbourhoods.

We started this investigation with an inventory of all the ‘hardware’ that is currently supporting the functions of the cities. A distinction was made between the urban functions ‘living’, ‘working’, ‘recreation’ and ‘transportation’. In describing all the material goods supporting or enabling these functions we made a distinction in ‘passive hardware’, which we defined as all structures (like a building shell or a road) that are fixed, not-movable and have a long depreciation period, and ‘active hardware’. The last category includes all installations (heating, ventilation and cooling), means of transport, distributions systems, etc, with depreciation periods of ten to fifteen years.
After finishing the listing and description of all types of hardware one finds in a city, we assumed that our imaginary city would have to adapt to the climate impacts described above and would have to use considerably less fossil fuel based energy, and would close its water cycles as much as possible. The necessary adjustments in structures and active hardware have been described in general terms for the levels ‘building’, ‘neighbourhood’ and ‘city’.

This resulted in a rich overview of possible directions for solutions, in which we subsequently made a grouping in clusters of related measures. It appeared that climate mitigation and adaptation influence almost all passive and active hardware in a city. This finding underlines again that climate change and mitigation measures will impact all aspects of our daily lives in the future. For buildings, the rise in peak temperatures and the required reductions in carbon dioxide emissions are the main effects that make changes in hardware necessary. On the level of neighbourhoods, city districts and the city as a whole the interactions between the increase in precipitation and the availability of water in general combined with mitigation provide most opportunities for synergetic measures.

4. Adaptation-mitigation synergies

Measures with potential for both mitigation and adaptation can be found on all planning levels in cities (building, neighbourhood and the entire city or conurbation, see Table 2). They range in scope from large and complicated, such as physical planning measures influencing the transport system of a city, to simple and localised, such as material use in buildings.

Several of the clusters of measures link the building and neighbourhood level. For example, rainwater buffers in buildings can supply local ponds with water, which in turn can be used as irrigation water in dry periods; energy buffers and daily or seasonal thermal storage in the neighbourhood will be connected to the energy provision of individual buildings. How elegant this may seem, this linkage gives rise to administrative and juridical difficulties, as these solutions cross the boundary between individual property and public space.

Apart from a list of synergies, the inventory also provided insights in possible conflicts between adaptive and mitigation measures. An obvious example is letting the sun into the building: a source of free energy in the cold season, but it may lead to a need for extra cooling in the warm season and can even lead to overheating. In the elaborated examples below it is suggested that some of these conflicts can be overcome by combining ambitious improvements of the energy efficiency, dwarfing the use of energy, with the use of ‘active hardware’ to make best use of available heat and cold.
### Table 2: Clusters of adaptation/mitigation measures

<table>
<thead>
<tr>
<th>level</th>
<th>measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>building</td>
<td>Adjustable building shell (climate screens) with efficient ventilation</td>
</tr>
<tr>
<td></td>
<td>Flexible use of space within buildings</td>
</tr>
<tr>
<td></td>
<td>Changes in building materials</td>
</tr>
<tr>
<td></td>
<td>Local water and energy buffers</td>
</tr>
<tr>
<td></td>
<td>Efficient heating and cooling</td>
</tr>
<tr>
<td></td>
<td>Reduction artificial lighting</td>
</tr>
<tr>
<td>neighbourhood</td>
<td>Buffers and collective systems for heat/cold</td>
</tr>
<tr>
<td></td>
<td>Water buffers en technologies for purification (closing water cycles)</td>
</tr>
<tr>
<td></td>
<td>Water-energy buffers</td>
</tr>
<tr>
<td></td>
<td>Physical planning buildings and screens</td>
</tr>
<tr>
<td></td>
<td>Physical planning neighbourhoods and green spaces and water bodies</td>
</tr>
<tr>
<td></td>
<td>Use of materials (albedo effect)</td>
</tr>
<tr>
<td>city</td>
<td>Strategic location of storage houses and logistics</td>
</tr>
<tr>
<td></td>
<td>Mixing urban functions</td>
</tr>
<tr>
<td></td>
<td>Dikes/quays and bicycle/public transport routes</td>
</tr>
</tbody>
</table>

### 5. Elaborated examples

**Buildings**

For buildings, the necessity to considerably increase the efficiency of energy use and to maintain the current level of comfort, also during heat waves, are important points of attention. An increase in the use of air-conditioning installations is undesirable and would lead to a waste of energy. Overheating can be prevented with passive building solutions, such as increasing the mass of materials in the structure of buildings or by using other means to increase the thermal mass, screens and passive ventilation during the night. In seasonal climates solutions need to be found for using the warmth of incoming sunrays in the cold season, while keeping the sun out in the summer season. This requires development of adjustable building shells. Currently research is being done on double skin facades and dynamic windows that increase energy efficiency (Boer, 2008, Stec, 2006). This research focuses on large scale application in utility buildings. However, similar solutions are also needed for application in houses. Even more radical solutions, such as houses or buildings that change their appearance in summer and winter could be developed.

In new, thermally well insulated, buildings individual regulation of the indoor climate will provide opportunities to save even more energy and improve user comfort.
Similar thoughts underlie the concept of flexible buildings. Currently there is much attention for constructing buildings that are flexible with regard to future use. Such buildings can be transformed from, for example, a hospital into an office building and visa versa with a minimum of investments (Brand, 1995). Climate change offers an opportunity to develop the concept of flexible buildings even further. Flexibility with regard to climate change can imply that the functions of part of a building can easily be changed in the future if the climate would make that necessary. Seasonal flexibility of buildings is an additional interesting concept. It would mean that dependent on the passive provision of heat or cold in a building, functions change over the seasons.

Even though lighting is not a major source of energy consumption in buildings, a better use of daylight provides easy opportunities for energy saving. The development of local regulation of the indoor temperatures, and of dynamic windows and regulated screens offers opportunities to provide users with the tools to regulate individually and locally their comfort level with regard to both light and temperature.

**Energy and water buffers**

Already now, adaptation to future extreme rainfall events gets considerable attention in the Netherlands. The main focus, however, is on infiltration, dimensions of sewerage systems and other means to get rid of the excess water. Rainwater reservoirs to store the water and keep it in the neighbourhood with various opportunities for use, provide more perspectives for the future. Rainwater reservoirs on top of, in or nearby buildings can provide gray water for toilet flushing etc. Decentralized purification can deliver water of high quality. If this would be used on a large scale, rainwater could play an even more important role in the water provision of the city. Until now regulations have restricted the introduction of decentralized water systems, but this may change in the future, when climate change and sea level rise may restrict the provision of clean water in Dutch cities because of increased salinisation of sources, while at the same time more rainwater will be available.

Obviously water reservoirs can play a role in cooling the city during extreme heat periods. Solutions are not only to be found in creating ponds between buildings, but water can also be used to cool buildings. Cooling towers can provide cool air in buildings, water can be applied to a water absorbent layer (a green roof or a material that functions as a sponge) on top of buildings, from where it evaporates and directly cools the building structure.

Creating reservoirs provides opportunities to use the water in decentralised energy systems. Storage of heat in reservoirs is a first option, but more research and demonstration projects will be needed to increase the efficiency of seasonal storage of heat and cold. Reservoirs can probably be better utilised in combination with heat pumps to use the presence of heat or cold in the water. For this solution to take effect, the efficiency of heat pumps need to be considerably improved to make them economically attractive.

Measures that use rainwater often cross the boundary between the private space (the house, a building) and public spaces (such as the street, a parking lot). For example, water storage under a parking lot uses public space, but the water may be used for cooling private buildings. Such a lay-out
may create problems with ownership that, if not taken into account, may become a barrier to innovative solutions.

**Building materials**

Building materials play an important role with respect to insulation and increasing the thermal mass of buildings (for energy saving and extreme heat), and for interception of precipitation. Increasing the capacity of buildings to buffer the flow of water from the roofs to the street can prevent flooding elsewhere in the city. Porous building materials used on the roof or on walls of buildings can at the same time function as insulation or provide cooling for the surroundings. Examples are green roofs with vegetation (EPA, 2009), but alternative materials may have the same function.

Advanced materials, such as phase change materials or thermo-chemical materials or other products will certainly play a role to increase the thermal capacity of buildings in the future. Also current technology solutions are possible, such as building elements that can be filled with water and be emptied again when necessary. All these solutions provided by changing building materials can contribute to energy savings in heating and cooling cycles.

**Physical planning**

Physical planning of cities is usually associated with taking adaptation measures (more green and water) and less to mitigation measures. However, the orientation of buildings is equally important for the functioning of solar panels on the roof, as it is for avoiding overheating. On a larger scale, probably the most important contribution of physical planning to prevent climate change is to avoid a separation of functions. Mixing functions (living, working, shopping, etc.) in a neighbourhood contributes to a decrease in transport demand. As the transport sector has limited possibilities to reduce its greenhouse gas emissions by other means reducing transport demand is an important measure for the sector. Even if we would have sufficient access to renewable electricity and electric cars, demand reduction would still be important for preventing congestion. Mixing urban functions (recreation and living, for instance) can also contribute to improving the local climate, by creating less uniformity in urban land use.

**Strategic location of warehouses and changes in logistics**

A climate robust distribution system would be able to cope with extremes in precipitation and the concomitant traffic disturbances, even in the extreme case of flooding. Reflecting on the design of such a system, we noted that, if well-designed, a climate robust distribution system might have positive impacts on energy consumption in the logistical chain and reduce air polluting emissions. Its concepts could resemble those of urban freight transport systems that some cities are currently developing. More elaboration is needed to clarify the exact linkages between logistics and adaptation.
Material use

The use of materials in public spaces influences the radiation balance of districts and cities. Reflective materials on roofs (“Cool roofs”), facades and roads reduce the need for cooling inside buildings and affect the outside temperatures. In California and other parts of the US “white roof campaigns” have been set up, with the arguments that with little or no investment energy will be saved as the need for switching on the air conditioning will be reduced.

For the countries like The Netherlands further research is needed into the mitigative and adaptive effectiveness of this type of measures. For the moment it seems that for individual buildings more energy can be saved by insulating the roof than by painting it white.

6. Conclusions

It is now essential to consider measures for climate adaptation together with mitigation measures. Solutions that are counterproductive are prevented, while beneficial synergies between measures can be exploited. All in all this will lead to a more efficient and more effective approach to the various challenges of climate change.

Many of the suggestions given in this paper need further elaboration. In the first place effectiveness evaluations are needed, but secondly feasibility studies need to be undertaken. Elaborating these solutions, will provide clarity about how integrated packages of measures will look like, and at the same time provide the basis for developing criteria for judging plans and strategies on the interconnected aspects of climate adaptation and mitigation.

It is not necessary to wait with the implementation of adaptation measures until the climate has changed. As some of the examples above demonstrate, adaptation measures can already now be integrated in measures that are taken because of other reasons.

Acknowledgement

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References

Boer, B.J. (2008). Zon-WEL; dynamische zonnegevel. ECN report ECN-E_08-012


Abstract

Recent activity in the development of future weather data for building performance simulation follows recognition of the limitations of traditional methods, which have been based on a stationary (observed) climate. In the UK, such developments have followed on from the availability of regional climate models as delivered in UKCIP02 and recently the probabilistic projections released under UKCP09. One major area of concern is the future performance and adaptability of buildings that employ exclusively passive or low-energy cooling systems. One such method, which can be employed in an integral or retrofit situation, is direct or indirect evaporative cooling. The effectiveness of evaporative cooling is most strongly influenced by the wet bulb depression of the ambient air, hence is generally regarded as most suited to hot, dry climates. However this technology has been shown to be effective in the UK, primarily in mixed-mode buildings or as a retrofit to industrial/commercial applications. Climate projections for the UK generally indicate an increase in the summer wet-bulb depression, suggesting an enhanced potential for the application of evaporative cooling. The paper illustrates this potential by an analysis of the probabilistic scenarios released under UKCP09, together with a detailed building/plant simulation of case study building located in the South-East of England. The results indicate a high probability that evaporative cooling will be a viable low-energy technique in the 2050s.

Keywords: evaporative cooling, climate change, building/HVAC modelling
1. Introduction

1.1 Cooling systems

Evaporative (or adiabatic) cooling is a process of reducing the temperature of the air by means of the evaporation of water via an adjacent surface. The cooling occurs through the absorption by the water of the latent heat of evaporation, hence there is no external transfer of heat. In building HVAC systems this is effected by means of sprays or contact pads, hence the ‘coefficient of performance’ (in comparison with a conventional refrigeration system) is mainly defined by the energy used in supplying the water. Evaporative cooling is a significant component of many low-energy cooling systems.

The simplest practical approach is the direct system, in which the cooled stream of air is introduced directly into the internal space. This is often used in industrial applications and is particularly suitable for a retrofit. Direct cooling means that the humidity within the zone is increased. The alternative method is to cool the supply air indirectly via a heat exchanger such as a plate or wheel configuration. This avoids the problem of increased humidity and also any health concerns regarding droplet contamination. The additional heat exchanger causes a reduction in the cooling available and adds an additional pressure drop to the system. Indirect cooling is easily incorporated into an air handling plant where it can be used either as the sole cooling source or combined with a separate conventional coil which provides additional cooling if necessary.

Indirect evaporative cooling systems are increasingly being specified in mechanically-ventilated and mixed-mode buildings. They are particularly effective when combined with a displacement ventilation distribution system, where the combination of low air flow rates and comparatively high supply temperature corresponds well with the indirect system characteristics.

1.2 System performance

The effectiveness of evaporative cooling depends critically on the capacity of the air stream to hold additional water vapour: most existing applications have been installed in hot, arid climates. Nevertheless these systems can be usefully applied in temperature climates such as the UK and other locations in Europe and there are a number of buildings where this technology has been applied in both mechanically-ventilated and mixed-mode buildings.

The adiabatic cooling of air by the evaporation of water is an isenthalpic process, hence the potential for cooling a stream of air is defined by the difference between the dry bulb temperature of the air and the saturation temperature corresponding to the air enthalpy. However, the latter is in practice very close to the wet bulb temperature so here we define the cooling potential of an air stream to be \( (t_{\text{dry}} - t_{\text{wet}}) \).
A practical humidifier (using a spray or a pad) will not be able to achieve complete saturation, but it is convenient to work with the concept of saturation efficiency, $\eta$ (Brandemuehl 1993), which is a function of the air mass flow rate assuming there is infinite capacity on the water-side. In the case of an indirect system the heat transfer from the moistened air stream to the room air supply can be characterised by a temperature effectiveness epsilon. The available cooling power is thus given by

$$Q = m c_p \eta \varepsilon (t_{dry} - t_{wet})$$

The saturation effectiveness of most devices is quite high, generally exceeding 90%. In an indirect system the temperature drop available is moderated by the heat exchanger. In many component models, these two functions are combined and modern high performance commercial units can have a combined efficiency of over 75%.

The question arises as to the future effectiveness of adiabatic cooling, given that air temperatures are predicted to rise, thereby increasing the cooling loads on buildings and the risk of summer thermal discomfort. In general terms, climate models point towards increasing temperatures, with drier summers and wetter winters. This suggests that there is a possibility that the summer wet bulb depression might increase, thus affording a higher potential for evaporative cooling in the future.

### 2. Analysis using climate projections

An analysis of the likely future cooling potential was undertaken using the recently available UK probabilistic projections UKCP09. In these projections, the change factors are not presented as deterministic values, but as probability density functions. The projections are available for three time slices (averages for a 30-year period centred on 2020s, 2050s and 2080s) and three emissions scenarios (low, medium and high). If a high time resolution (daily or hourly) is required, a weather generator is available (Jones et al 2009) which has the spatial resolution of a 5 km grid. The weather generator produces two output sets; control weather files which represent the reference period 1961-1990, together with the chosen scenario output. The user has control over how the relevant pdfs are sampled: in this work a random sampling was employed, but other regions of the distribution are available. Two locations were used --- the south-east of England (Heathrow) and a Scottish location (Glasgow) and run for the medium emissions scenario and the 2050s timeslice. In each case, 100 files were generated to account for the variability of the calculation of the change factors, each of these files contained 30 years of hourly data, allowing for the inter-annual variability in the weather.

The hourly cooling potential for each of these output files was calculated, but given that buildings are most likely to require cooling during the summer period (here April to September) and that the plant is likely to be in operation only during occupied hours (07:00 to 19:00) the results presented below are for these restricted periods. The summary data are presented in Table 1 and shown graphically as frequency distributions (for 50 bins) in Figures 1 and 2.
Table 1. Summer daytime cooling potential for London Heathrow and Glasgow

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>std deviation</td>
</tr>
<tr>
<td>London</td>
<td>786</td>
<td>89 (11%)</td>
</tr>
<tr>
<td>Glasgow</td>
<td>528</td>
<td>61 (12%)</td>
</tr>
</tbody>
</table>

Figure 1: Summer daytime cooling potential for Heathrow

Figure 2. Summer daytime cooling potential for Glasgow
For both locations there is a significant increase in predicted cooling potential over this period, with a mean increase of 49% for Heathrow and 36% for Glasgow. Whilst there is a clear indication that the effectiveness of the evaporative cooling process might increase, there is also an indicated upward shift in both temperatures: the mean wet bulb temperature is likely to rise by approximately 2 K. There is therefore a possibility that, particularly in the case of an existing building, an evaporative cooling system might cease to able to maintain acceptable thermal comfort conditions in the future. Accordingly a detailed combined building/plant simulation was undertaken of a commercial mixed-mode building to gain an initial perspective on this problem.

3. Simulations using case a study building

3.1 Zone description

The case study building selected for detailed analysis was a single-zone office conforming to the German standard VDI 6020 (VDI 2001). This model has been subjected to extensive calibration and and validation calculations and consists of a thermally heavy construction with a single facade open to the surroundings. The zone has a floor area of 17.5 m² and a large glazed area on the outside wall. This zone was chosen as it represents a challenging test for any low-energy cooling system. The zone was simulated using code based on the 3TC lumped parameter model (Tindale 1993) which has also been widely validated and used in other simulation-based studies. Being a lumped-parameter model, 3TC has fast execution times, making it particularly suitable for the large number of runs required in probabilistic studies.

The case study zone was located in the South-East of England and the zone model was combined with, firstly, a conventional all-air cooling system and secondly with an evaporative cooling plant both with a nominal maximum capacity of 10 kW.

3.2 Performance criteria

As control of temperature in the zone was effected by mechanical cooling systems, a measure of thermal discomfort was used based on Fanger's concept of Percentage Persons Dissatisfied (PPD). Thermal comfort was recorded on an hourly basis: however, rather than registering the number of hours per annum for which the discomfort exceeded some threshold (normally 10%), a weighted approach was used whereby one point was allocated for each increment of 10% which occurred over the threshold value. Hence if the PPD was in the range 10-20% one point was incurred, 20-30% would incur two points and so on. A very similar scheme was adopted by the Government Building Agency in the Netherlands (de Wit 1996) and the index is referred to here as GBA. For a building to be assessed as having acceptable performance the limiting value of this index should be 150.

The GBA index was logged for all the occupied hours (weekdays, 08:00 to 18:00): in addition the number of occupied hours when the temperature exceeded 25°C (hrs25+) was also recorded to give an alternative perspective on the ability of the cooling plant to control internal temperatures.
3.3 Simulation output

The key objectives of these simulation runs were to establish if, at this level, evaporative cooling could be maintained or increased in the context of a changing climate but also to investigate whether or not thermally comfortable conditions could be maintained with the same plant configuration in the face of rising temperatures. The simulation runs were carried out using CIBSE format weather files (CIBSE 2009) derived from runs of the UKCP09 hourly weather generator for the control (1961-1990) period and for the medium emissions scenario and the 2050s timeslice. For both sets of runs, 3,000 yearly simulations were run to capture the full variability in the climate projections.

The cooling supplied to the zone by the evaporative system is shown in Figure 3 for both the control and scenario periods. It can be seen that the future climate does lead to greater cooling energy supplied to the space, but that when detailed plant performance is analysed in the context of a modelled zone, the increase (22.7% on average) is rather less than that suggested by climate data analysis.

![Figure 3: Cooling energy supplied to office zone](image)

The ability of the evaporative cooling plant to maintain thermal comfort was reduced by the rise in cooling load. Running the model with the control weather files using a conventional cooling plant, the two measures of discomfort (hrs25+ and GBA) both registered zero. Using evaporative cooling, the average number of occupied hours exceeding 25°C was 2, and the mean value of GBA was 13.1. When the model was run with the future climate the mean value of hrs25+ rose to 3.3 and the value of GBA to 36.4. It was noted that the maximum value of GBA recorded by the probabilistic runs was 141, still within the limiting value of 150. A probability density function for the values of GBA is shown in Fig. 4.
Working with the UKCP09 probabilistic scenarios, it has become apparent that the variability observed depends very much on the performance parameter being investigated. Measures of thermal comfort, for instance, generally have a much higher spread of values as shown in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mean</strong></td>
<td>2190.4</td>
<td>2688.0</td>
</tr>
<tr>
<td><strong>std deviation</strong></td>
<td>54.76 (2.5%)</td>
<td>103.0 (3.8%)</td>
</tr>
<tr>
<td><strong>Cooling energy</strong> (kWh)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GBA index</strong></td>
<td>13.1</td>
<td>36.4</td>
</tr>
<tr>
<td></td>
<td>6.7 (51%)</td>
<td>21.1 (58%)</td>
</tr>
</tbody>
</table>

### 4. Conclusions

An analysis of the output of the UKCP09 probabilistic climate projections for the control (196-1990) and the 2050s timeslice with medium emissions scenario has shown that future climates will probably offer a greater potential for the use of evaporative cooling. The analysis was carried out for two locations, Heathrow in the South-East of England and Glasgow, representing a more northern UK climate. A measure of evaporative cooling potential, the difference between the dry- and wet-bulb temperatures during summer daytime hours, suggested that the cooling potential could be up to 49% higher for the scenario investigated. This is in contrast to conventional cooling systems, whose coefficient of performance will reduce in the face of rising ambient temperatures.
Although the effectiveness of evaporative cooling plant might be increased, the rising outdoor dry bulb temperatures will increase cooling loads and make the maintenance of thermal comfort more difficult. A combined building/plant simulation of a single office zone with evaporative cooling was run with a set of probabilistic weather files representing the present and future (2050s) climates for South-East England. The number of files (3,000) was sufficient to ensure that both the year-on-year weather variability and the climate modelling uncertainty were both captured.

The simulations confirmed that the plant delivered an increase in cooling to the zone, but that the increase was less than that suggested by a simple climate analysis. A small increase in thermal discomfort occurred, but this was well within the limits of acceptable performance. However, the simulations were only carried out for a single case study building, and the conclusions, with regard to thermal comfort in particular, will not in general apply to other building configurations and uses. Further work is in progress to expand the scope of case study buildings to cover a much wider spectrum of building use and thermal performance characteristics.

Viewed within the context of the time span covered by the simulations, around sixty years, it is likely that any cooling plant would be upgraded or retrofitted. In this study, the plant configuration and capacities were maintained but it would be conceivable that over the lifetime of the building that this might not be the case. The output of an evaporative cooling plant could be increased by utilising a larger adiabatic saturator and (in the case of an indirect system) heat exchanger. Increasing the capacity of such a plant would also mean a higher air mass flow rate, as there is no possibility of reducing supply air temperatures. Overall, it is concluded that evaporative cooling systems will probably function effectively in the context of a changing climate and therefore to continue to be an effective solution for many mechanically-cooled and mixed-mode buildings.

References


VDI 6020 2001. “Requirements on a methodology for the calculation of thermal and energy simulation of building and plants”.


Chartered Institution of Building Services Engineers (CIBSE) 2009. “CIBSE TRY/DSY Hourly Weather Data Set - 14 sites” CIBSE, London


List of symbols

- $c_p$: specific heat of moist air  [kJ kg$^{-1}$ K$^{-1}$]
- $m$: mass flow rate of air  [kg s$^{-1}$]
- $Q$: cooling power [kW]
- $t_{dry}$: dry bulb air temperature [°C]
- $t_{wet}$: wet bulb air temperature [°C]
- $t_{sat}$: saturation temperature corresponding to air enthalpy [°C]
- $\eta$: saturation efficiency [-]
- $\varepsilon$: temperature effectiveness [-]
Sustainable Climate Adaptation: The Critical Link between Sustainable Development & Climate Change in the Built Environment

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Abstract

As asked directly, at a Dublin meeting, about how the relationship between Climate Change and Sustainable Development had been dealt with in the 2007 WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report where it was mentioned almost as an afterthought, Dr. Rajendra Pachauri, IPCC Chair, replied that he was personally disappointed that something more substantial had not been done to explore this link. He seemed surprised to receive the question. The 2009 United Nations Framework Convention on Climate Change (UNFCCC) Summit, which was held in Copenhagen from 7th to 19th December, was chaotic and its outcome was divisive. Since then, it has been particularly noticeable that the IPCC, Dr. Pachauri's position within that organization, and the Science of Climate Change itself have all been targeted by an increasing number of vocal sceptics in Developed Countries, particularly the U.S.A. If anything is clear, it is that the Politics of Climate Change must now be carefully dissected and analyzed before an effective global response to Climate Change can be properly mobilized and reliably implemented. Learning from these events, the urgent priority for those organizations/individuals involved in the design, construction, management or operation of the Built Environment... is to quickly elaborate a Climate Change Strategy which is 'politically' and 'technically' appropriate for the near and long terms while, at the same time, avoiding any short-term roadblocks to progress. This Paper explores the symbiotic relationship between the concept of Sustainable Human and Social Development and the reality of Climate Change... a link which is critical to the development of that elusive consensual global response... and essential for the effective implementation of a Built Environment Climate Change Strategy. Fortuitously relevant, in these interesting times... having commenced in June 2008... the on-going development of a CIB Working Commission 108 ('Climate Change and the Built Environment') Project will also be outlined, which will result in the publication of the Report: 'Sustainable Climate Change Adaptation in the Built Environment', during 2010.

Keywords: 2009 UNFCCC Copenhagen climate summit, climate change politics, climate change adaptation, sustainable human & social development, new CIB W108 report
1. Introduction

Asked directly, at a Dublin meeting[1], about how the relationship between Climate Change and Sustainable Development had been dealt with in the 2007 WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report - where it was mentioned almost as an afterthought - Dr. Rajendra Pachauri, IPCC Chair, replied that he was personally disappointed that something more substantial had not been done to explore this link. He seemed surprised to receive the question.

The 2009 United Nations Framework Convention on Climate Change (UNFCCC) Summit, which was held in Copenhagen from 7th-19th December, was chaotic ... and its outcome was divisive. Since then, it has been particularly noticeable that the IPCC[2], Dr. Pachauri's position within that organization, and the Science of Climate Change itself ... have all been targeted by an increasing number of vocal sceptics in Developed Countries, particularly the U.S.A.[3] [4] If anything is clear, it is that the Politics of Climate Change must now be carefully dissected and analyzed before an effective global response to Climate Change can be properly mobilized and reliably implemented.

Learning from these events, the urgent priority for those organizations/individuals involved in the design, construction, management or operation of the Built Environment ... is to quickly elaborate a Climate Change Strategy which is 'politically' and 'technically' appropriate for the near and long-terms ... while, at the same time, avoiding any short-term roadblocks to progress.

This Paper explores the symbiotic relationship between the concept of Sustainable Human and Social Development and the reality of Climate Change ... a link which is critical to the development of that elusive consensual global response ... and essential for the effective implementation of a Built Environment Climate Change Strategy.

Fortuitously relevant, in these interesting times ... having commenced in June 2008 ... the on-going development of a CIB Working Commission 108 ('Climate Change and the Built Environment') Project will also be outlined, which will result in the publication of the Report: 'Sustainable Climate Change Adaptation in the Built Environment', during 2010.

2. Towards the accurate understanding of 'Sustainable Development'

2.1 An open baseline definition & its rational evolution

Turning our attention back to the last quarter of the 20th Century ... not as far back as the Stockholm Declaration of the United Nations Conference on the Human Environment, which met in Sweden, from 5-16th June 1972 ... and, in which document, much of the text in the later 1992 Rio Declaration on Environment & Development can be seen ... but to the 1987 Report of the World Commission on
Environment and Development (WCED): 'Our Common Future'[5], which was chaired by Gro Harlem Brundtland (Norway), with Mansour Khalid (Sudan) as Vice-Chair.

This definition of 'Sustainable Development' appears at the beginning of Chapter 2 in the 1987 Report:

"Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and

- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."

Many people in Developed Countries may only be familiar with the first sentence above. But, in isolation, this renders the concept of 'sustainable development' so vague that it is almost meaningless. And let us be honest with ourselves ... this ambiguous definition has been comprehensively rejected by the Developing and Least Developed Regions of the world ... the concept being viewed as an unaffordable luxury and/or a means of continued domination and control by the 'North', i.e. those same Developed Countries.

Most people in Developed Countries, however, may be surprised by the second, and more important, half of the WCED/Brundtland Definition which adds shape and dimension to that initially vague concept. The 'essential needs' of the world's poor - not their irresponsible 'desires' - must be given priority in all sustainable development strategies. Furthermore, as most of our traditional institutions are inherently inefficient and wasteful of resources, we must choose to re-organize and transform our different societies in order to properly implement the concept. Finally, it must be acknowledged that there are limits to technology ... the belief in some magical techno-solution in 30 or 40 years time must not be allowed to deflect us from taking action today!

It is very clear, therefore, that it was always intended that there would be more than 3 Aspects of Sustainable Development (Environmental, Social and Economic) to be identified and examined ... additionally, for example, Institutional, Political and Legal Aspects. How was it ever possible to bring into existence that ubiquitous and over-simplistic 3-Circle Diagram?!

The 1987 WCED/Brundtland Report continues a little further on ...

'The satisfaction of human needs and aspirations is the major objective of development. The essential needs of vast numbers of people in developing countries - for food, clothing, shelter, jobs - are not being met, and beyond their basic needs these people have legitimate aspirations for an improved quality of life. A world in which poverty and inequity are endemic will always be prone to ecological and other crises.
Sustainable Development requires meeting the basic needs of all and extending to all the opportunity to satisfy their aspirations for a better life.

Sustainable Development is the greatest challenge ahead of us in this already troubled 21st Century... a century which started so tragically... from 9-11 in New York ... to Bali, Casablanca, Istanbul, Madrid, Sharm-el-Sheikh, London, Kusadasi and Mumbai... with the wars in Iraq, Afghanistan and Occupied Palestine still unresolved.

Sustainable Development is an intricate, open, dynamic and evolving concept ... and a clear choice must be made by policy-makers and practitioners: decide to pursue the detailed, rational elaboration of this concept ... with the aim of practical and effective implementation ... or of intellectual self-gratification alone.

### 2.2 Practical & effective implementation

In order to make 'real' progress ... how can we establish, agree upon and achieve a wide international consensus on what the 'basic needs of all' are? And with some precision? Is there an internationally recognized document, already long in existence, where these 'basic needs' are not only specified for every individual person, but are protected and guaranteed as rights? Yes, there is ... the 1948 Universal Declaration of Human Rights (UN OHCHR) ... and these needs, therefore, can also be described as being 'responsible'.

Reading through the 1948 UDHR, it is helpful if a distinction is made between human rights and social rights ...

**Social Rights:**

Rights to which an individual person is legally entitled, e.g. the right to free elementary education (Art.26(1), UDHR), but which are only exercised in a social context with other people, and with the active support of a competent legal authority, e.g. a Nation State.

Commentary: In contrast to Human Rights, it is not protection from the State which is desired or achieved, but freedom with the State's help.

Social Rights, as distinguished here, include and extend beyond current understandings of civil, political, economic, social and cultural rights.

This is why, almost a generation after the 1987 WCED/Brundtland Definition of Sustainable Development ... Sustainable Design International, has defined Sustainable Human & Social Development[6] as follows ...
'Development which meets the responsible needs, i.e. the Human & Social Rights*, of this generation - without stealing the life and living resources from future generations, especially our children ... and their children ... and the next five generations of children.'

*As defined, in international law, by the 1948 Universal Declaration of Human Rights (UN OHCHR).

Inspired by the Culture of the North American Indigenous Peoples ... this definition also incorporates the concept of '7 Generation Thinking'.

For a sizeable group of vulnerable people in all of our societies, the sole route of 'access' to the human and social rights set down in the 1948 Universal Declaration of Human Rights ... is the 2006 UN Convention on the Rights of Persons with Disabilities, which became an International Legal Instrument on 3rd May 2008 ... just short of 60 years after the UDHR was adopted on 10th December 1948!

A third International Legal Instrument to be placed at the core of this framework of Rights, i.e. basic & responsible needs ... is the 2001 Universal Declaration on Cultural Diversity (UNESCO) which was adopted in Paris, on 2nd November 2001 ... shortly after the World Trade Center (9-11) Incident in New York, on 11th September 2001.

Paris, at the end of 2001, presented the world with a unique opportunity...

- to reject outright the theory of the inevitable clash of cultures and civilizations; and

- to reaffirm the unshakable conviction that inter-cultural dialogue is the best guarantee of peace.

The Universal Declaration on Cultural Diversity raises cultural diversity to the level of the common heritage of humanity ... as necessary for our species as biodiversity is for nature ... and makes its defence an ethical imperative which is robustly linked to, and cannot be separated from, respect for the dignity of every individual person.

So ... beginning with this core framework ... it is possible to construct a larger and more elaborate lattice of inter-connected International Rights Instruments which specify, in greater detail, the 'basic needs of all'. This is the foundation of SDI's more practical and robust second-generation definition of Sustainable Human & Social Development.
Very quickly ... we can next move to roll out the full 'Sustainability' Agenda (not the far more limited and feeble 'Green' Agenda) ... commencing the serious task of transforming our Human Environment (including the built, virtual, social and economic environments ...) ... by closely monitoring and gradually improving 'real' Sustainability Performance using a Monitoring, Reporting & Verification Toolkit which currently comprises:

- Sustainability Impact Assessment (SIA);
- Qualitative & Quantitative Sectoral Performance Indicators;
- Benchmarking & Target Setting;
- Stringent Performance Evaluation;
- Independent Verification & Accurate Reporting.

We can also now confidently develop a 'Sustainability' Strategy concerning Climate Change, including Extremes and Variability, which is suited to and appropriate for the Built Environment, i.e. anywhere there is, or has been, a man-made or wrought (worked) intervention by humans in the natural environment, e.g. cities, towns, villages, rural settlements, services, transport systems, roads, bridges, tunnels, and cultivated lands, lakes, rivers, coasts, seas, etc ... including the Virtual Environment ... for the near-term (up to 2035) and the long-term (up to and beyond 2100)[7].
3. Climate change politics - From 2007 Bali consensus to a divisive Copenhagen in 2009

The UNFCCC Climate Summit held in Bali, Indonesia, from 3rd-15th December 2007 ... resulted in a strong global consensus in favour of immediate and concerted action on climate change ... and a sharply worded document, the Bali Action Plan[8] - key parts of which state ...

' The Conference of the Parties,

Resolving to urgently enhance implementation of the Convention in order to achieve its ultimate objective in full accordance with its principles and commitments;

Reaffirming that economic and social development and poverty eradication are global priorities;

... Recognizing that deep cuts in global emissions will be required to achieve the ultimate objective of the Convention and emphasizing the urgency to address climate change as indicated in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change;

1. Decides to launch a comprehensive process to enable the full, effective and sustained implementation of the Convention through long-term cooperative action, now, up to and beyond 2012, in order to reach an agreed outcome and adopt a decision at its fifteenth session, by addressing ...

(a) A shared vision for long-term co-operative action, including a long-term global goal for emission reductions ... in accordance with the provisions and principles of the Convention, in particular the principle of common but differentiated responsibilities and respective capabilities;

(b) Enhanced national/international action on mitigation of climate change ... 

(c) Enhanced action on adaptation ...

(d) Enhanced action on technology development and transfer to support action on mitigation and adaptation ...

(e) Enhanced action on the provision of financial resources and investment to support action on mitigation and adaptation and technology cooperation ... '
Just a few weeks later, on 12th February 2008, in New York ... Ambassador John Ashe, Permanent Representative of Antigua & Barbuda to the United Nations, delivered an important Statement ... on behalf of the Group of 77 & China (comprising 130 countries) ... at the Thematic Debate of the U.N. General Assembly: 'Addressing Climate Change - The United Nations and the World at Work'. Fully reflecting and supporting the Bali Action Plan, this Statement clearly set out the Climate Change Priorities for the Developing and Least Developed Countries, including the Small Island Developing States (SIDS). It included the following important extract...

'Climate Change as a Sustainable Development Challenge

2. Mr. President, the Group of 77 and China is of the view that discussions on climate change should be placed within the proper context of sustainable development. It is imperative that our discussion reinforces the promotion of sustainable development...

3. We must not lose sight of the fact that climate change is a sustainable development challenge. As such we should adhere steadfastly to the Rio principles, in particular the principle of common but differentiated responsibilities. We must take fully into account that poverty eradication, economic and social development are the paramount priorities of developing countries...

4. Mr. President, urgent action is needed now to fully implement the commitments under the Convention and the Kyoto Protocol, especially commitments on financing for adaptation, technology transfer and capacity building, if we are to make progress towards the achievement of the sustainable development goals of developing countries...

8. Urgent action is particularly needed on commitments, as climate change threatens the livelihoods of the very poor and vulnerable developing countries, in particular Africa, the Least Developed Countries, the Land-Locked Least Developed Countries, Small Island Developing States, and disaster prone developing countries. The G77 and China is of the view that while addressing the challenge of climate, the most affected countries and most vulnerable countries should be given adequate attention and support.

5. Developed countries Parties must take the lead in addressing the implementation gap, since the extent to which developing countries Parties can effectively respond to the challenge depends on the effective implementation by developed country Parties of their commitments relating to financing and technology transfer.'

The Developed Countries, i.e. those listed in Annex I of the 1992 UN Framework Convention on Climate Change, did not listen to the words of John Ashe. This helps to explain the fracture of the 2007 Bali Consensus at Copenhagen, in December 2009 ... the sharp division between the 'have's' and the 'have-not's' of our small planet.
Within Developed Countries ... there may be a certain comfort, at an intellectual level, in linking Sustainable Development and Climate Change. However, in vulnerable Developing Countries this link is critical ... where poverty eradication, and economic and social development are paramount priorities. All are 'responsible needs' which are specified and supported by International Law. Yet, the Developed Countries persist in disregarding their legal obligations under Articles 2.3 and 3.14 of the 1997 UNFCCC Kyoto Protocol ... and, more importantly, evading their historical responsibility for causing the problem of Anthropogenic Climate Change in the first place.

Closer to home, in the European Union Member States[9], far too much emphasis is being placed on fully exploiting the various 'flexibility mechanisms' within the UNFCCC Process ... rather than on direct and proper compliance with their individual Kyoto Mitigation Commitments[10]. There is little or no interest in Adaptation. Meanwhile, the reality shown by the latest analysis of observations from the World Meteorological Organization's Global Atmosphere Watch (GAW) Programme[11] is that the globally averaged mixing ratios of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) reached new highs in 2008 with CO2 at 385.2 parts per million, CH4 at 1797 parts per billion (ppb) and N2O at 321.8 ppb ... higher than those in pre-industrial times (before 1750) by 38%, 157% and 19%, respectively!

4. To mitigate or adapt? - Urgently prioritizing a strategy for the built environment

Before the official announcement of the independent InterAcademy Council (IAC) Review of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) ... clear indications had been given, at recent meetings in Dublin[12] [13], that serious question marks hovered over the IPCC, its 2007 4th Assessment Report, Dr. Pachauri's position within the IPCC ... the actions of many of the Non-Governmental Organizations (NGO's) who were at Copenhagen ... and the Science of Climate Change itself (refer, for example, to revelations following the hacking of e-mails and other data from a server in the University of East Anglia's Climate Research Unit in England, and the irregularities/errors in the IPCC's 4th Assessment Report).

The Copenhagen Accord[14] was a political agreement between a small number of Heads of State, Heads of Government, Ministers, and Heads of Delegation - Brazil, South Africa, India and China (BASIC) and the USA - who attended the Copenhagen Climate Change Summit, which concluded on Saturday, 19th December 2009. At the time of writing, many countries have made voluntary submissions, i.e. they are not legally binding, to Appendices I and II of the Accord.

A general overview[15] of the submissions made by Developed Countries, however, reveals the following about the voluntary emissions targets being undertaken ...

- they are highly conditional on the performance of other countries;

- they are very disappointing, being far below what is required to cap the planetary temperature rise at 1.5 degrees Celsius; and
- there is no consistent emission base year ... varying from 1990 and 1992, up to 2000 and 2005.

This is very far from being a signal of serious intent from Developed Countries ... and is not ... in any way, shape or manner ... an acceptance of historical responsibilities. It would be reasonable, therefore, to surmise that the process of achieving a global, legally binding, consensus agreement on greenhouse gas (GHG) emission reduction targets will be long and difficult. The Climate Change Mitigation Agenda is, to put it mildly, fraught with problems ... and has an unclear future in the short term.

On the other hand, anyone involved in the design, construction, management or operation of the Built Environment must think 'long-term' ... the minimum life cycle for a sustainable building should be at least 100 years. Today in Dublin, buildings which are 250 or 350 years old still look remarkably good, and are well capable of fulfilling an important function within the social and economic environments of the city. 'Politically' and 'technically', therefore, it would be more appropriate for the built environment if we were concerned with the long-term Adaptation Agenda ... rather than a problematic, short-term Mitigation Agenda. But, in terms of a building, is there really a clear difference between measures undertaken for the purpose of mitigation and those undertaken for adaptation? For example, measures to incrementally improve energy efficiency and conserve energy, in accordance with short-term legally binding targets, will serve to mitigate CO2 emissions ... but the same measures will also serve to adapt the building to rapidly dwindling supplies of climate-damaging fossil fuels. The long-term perspective will exert pressure for more radical actions in the short-term. But, should we not already be undertaking these sorts of measures as part of the Mainstream Sustainability Agenda ... in order to increase building durability and prolong life cycle?

Generally... Climate Change Adaptation[16] encompasses urgent and immediate short, near and long-term actions at local, national, regional and international levels to reduce the vulnerability and strengthen the resilience of the Human Environment, including ecological and social systems, institutions and economic sectors ... to present and future adverse effects of climate change and the impacts of response measure implementation ... in order to minimize the local threats to life, human health, livelihoods, food security, assets, amenities, ecosystems and sustainable development.

More specifically ... Built Environment Climate Change Adaptation[17] means reliably implementing policies, practices, projects and institutional reforms in the Built Environment ... with the aim of reducing the adverse impacts and/or realizing the benefits directly/indirectly associated with climate change, including variability and extremes ... in a manner which is compatible with Sustainable Human and Social Development.

Climate Change Adaptation is one of the most important drivers for Sustainable Design!
5. How 'Sustainable' are built environment adaptation projects?

In Ireland, it has been proposed ... as an Adaptation Project[18] which will cost approximately €600 million, devour many material resources and have an adverse environmental impact ... to divert water from the Shannon, a large river in the mid-west of the country ... to Dublin, the capital city, which is located over 100 kilometres away on the east coast ... in order to deal with the expected shortage of water which will be caused, among 'other relevant factors', by future climate change.

But ... just how 'sustainable' is this Adaptation Project, if the following 'other relevant factors' are considered?

i) Since the 1960's ... a dysfunctional and corrupt Spatial Planning System in the Dublin City Region has actively encouraged an uncontrolled, urban and suburban horizontal sprawl to take place. Today, this pattern of development remains unchecked.

ii) At this time, there are still no residential water charges in Dublin. The concept of water conservation is, therefore, almost unknown among householders.

iii) There are enormous un-intended losses, i.e. leaks, from the public potable water distribution system ... approximately 40% even in the good times, and recently, well in excess of 60% following the National Snow Emergency in Ireland.

iv) Water supplied to houses in the Dublin City Region is not yet metered. There is no urgency, therefore, in locating and repairing water leaks which occur between the private property boundary of a house and the house itself.
v) There are no requirements in Ireland's National Building Regulations to harvest any rainwater in any buildings, or on any hard surfaces in the vicinity of those buildings.

vi) In 2005-2006, at the height of the Celtic Tiger Economic Boom ... the existing foul and storm water drainage infrastructure in the City Region[19] was already stretched to keep pace with the 'wild' demands for new development land. Overloading of the existing systems was evident from a marked deterioration in water quality, increased risks of flooding and pollution, and concerns that the drainage system and sewage treatment plants had insufficient capacity to cater for future development.

vii) Sustainability Impact Assessment (SIA) ...

' a continual evaluation and optimization assessment - informing initial decision-making, or design, and shaping activity/product/service realization, useful life and termination, or final disposal - of the interrelated positive and negative social, economic, environmental, institutional, political and legal impacts on balanced and equitable implementation of Sustainable Human & Social Development '

... is not yet a standard procedure, at any level, within national, regional and local Authorities Having Jurisdiction (AHJ's). If it were, the most glaring flaw in this project would rapidly be identified. There is no comprehension at all, in the minds of Dublin City's decision-makers, that water is a very valuable, but limited, resource!

6. CIB W108 report: 'Sustainable Climate Change Adaptation in the Built Environment'

Timely, directly relevant and urgently needed ... the purpose of this Report is to stimulate thought and discussion, within the global Built Environment research, innovation and design communities, on these and other issues connected to an effective, 'politically' and 'technically' appropriate sectoral response to the real threat of Climate Change. The project itself was initiated at a Nantes (France) Meeting of Working Commission 108: 'Climate Change & the Built Environment', held in June 2008.

The Report will comprise 2 Parts:

a) I - International Synthesis on Sustainable Climate Change Adaptation;

b) II - National Perspectives on Sustainable Climate Change Adaptation (at the time of writing, involving approximately 10-12 countries).

The National Perspectives will contain information on the following ...

- meteorological data, and local climate-related hazards;
- proposed/implemented climate change mitigation and adaptation measures;
7. Conclusions

The Link between the reality of Climate Change in the Built Environment and the implementation of Sustainable Human and Social Development, as properly understood to be rooted in International Law, is complex and synergetic ... and critical for...

- Developing Countries ... the paramount priorities of which have been clearly stated to be: 'poverty eradication, and economic and social development' ... responsible needs specified, as rights, under International Law;

- Developed Countries ... acknowledging their historical responsibilities and recognizing the rights of Developing Countries ... will be key components in any future, legally binding, consensus global agreement on the GHG emission reduction targets required to cap the planetary temperature rise at 1.5 degrees Celsius.

This Link is essential. To be successful, National Adaptation Strategies, Programmes and Projects must be informed, in a meaningful way, by the concept of Sustainable Human and Social Development... and, prior to implementation, filtered through the lens of a comprehensive Sustainability Impact Assessment (SIA).

8. Notes & information sources


The title of Dr. Rajendra Pachauri's Keynote Address, on 1st June 2007, was 'Assessment of Climate Change: How Should Human Society respond ?', where he outlined the findings of the IPCC's 4th Assessment Report, published in May 2007. This question was posed by CJ Walsh, Sustainable Design International, during the Question & Answer Session which followed.
At a UN Press Conference (2010-03-10) ... Secretary-General Ban Ki-moon and the IPCC Chair, Dr. Pachauri, announced that the IPCC will undergo an independent and comprehensive review by the InterAcademy Council (IAC), a multi-national organization of the world's science academies. Based on an article by the UN News Service and an IAC Press Release - both dated 10th March 2010.


Conducted from 23rd-27th March 2008, the results of this survey were based on telephone interviews with 1,502 national adults, aged 18 years and older. Maximum margin of sampling error is ±3 percentage points.


Conducted from 5th-8th March 2009, the results of this survey were based on telephone interviews with 1,012 national adults, aged 18 years and older. Maximum margin of sampling error is ±3 percentage points.


Adopted at the Conference: 'Designing for the 21st Century III', which was held in Rio de Janeiro, Brazil, from 7th-12th December 2004 ... and organized by Adaptive Environments in Boston (USA) & Centro de Vida Independente do Rio de Janeiro (CVIRio). The Declaration, drafted by CJ Walsh, Sustainable Design International ... can be accessed and downloaded at: http://www.sustainable-design.eu/sustain/documents.htm#rio-social


Committee, an author team composed primarily of members of the research community, and numerous other meeting participants and external reviewers who provided extensive comments during the expert review process.


Conducted from 28th August-17th September 2009, the results of this Special Survey No. 322 were based on face-to-face interviews with 26,719 adults, aged 15 years and older, in all 27 European Union Member States. Maximum margin of sampling error is ±3.1 percentage points. Published in November 2009.


The fifth in a series of bulletins, dated 23rd November 2009, from the World Meteorological Organization's Global Atmosphere Watch (GAW) Programme ... which shows the levels of the six specified Kyoto Greenhouse Gases in the atmosphere using global observations during 2008. Prepared and distributed by the Secretariat of the World Meteorological Organization (WMO), in cooperation with the World Data Centre for Greenhouse Gases at the Japan Meteorological Agency and the GAW Scientific Advisory Group for Greenhouse Gases, with the assistance of the NOAA Earth System Research Laboratory.


Having attended the 2009 Copenhagen Climate Summit ... Monsieur Brice Lalonde, Chair of the Sustainable Development Roundtable for the Organization for Economic Co-Operation and Development (OECD) and former French Minister for Environment ... and Ms. Fiona Harvey, London Financial Times Environmental Editor ... presented personal perspectives on the future direction of international climate change negotiations. The IIEA Seminar was held on Thursday, 18th February 2010.
In his Keynote Address, Lord Anthony Giddens (GB) discussed the political complexities of combating Climate Change. This IIEA event was held on Tuesday, 23rd February 2010.

A political agreement between a small number of Heads of State, Heads of Government, Ministers, and Heads of Delegation attending the Copenhagen Climate Change Summit, which concluded on Saturday, 19th December 2009. The Accord ... outside the framework of the 1992 Convention and the legally binding 1997 Kyoto Protocol ... was noted by, but was not an official decision of, UNFCCC COP 15. No official document reference number.

The information from each country, or group of countries, concerns their quantified economy-wide greenhouse gas emission targets for 2020. Submissions can be accessed and downloaded at: http://unfccc.int/home/items/5264.php

This definition is adapted from those provided in Non-Paper No.53, dated 2009-11-06, of the Contact Group on Enhanced Action on Adaptation and Its Means of Implementation ... which was presented to a meeting in Barcelona (resumed seventh session), from 2nd-6th November 2009, of the Ad-Hoc Working Group on Long-Term Co-Operative Action under the 1992 United Nations Framework Convention on Climate Change.

This definition is adapted from those provided in European Environment Agency (EEA) Technical Report No.13 of 2007: 'Climate Change - The Cost of Inaction and the Cost of Adaptation' ... and earlier EEA documents. Published by the Office for Official Publications of the European Communities. Luxembourg.

Described as a 'pilot climate change adaptation project' on the UNFCCC's WebSite Database relating to the Nairobi Work Programme ... information concerning this Project can be accessed and downloaded at: http://www.watersupplyproject-dublinregion.ie


[16] Definition of 'Climate Change Adaptation'.

[17] Definition of 'Built Environment Climate Change Adaptation'.

[18] Inter-Basin Water Transfer Project from Lough Ree, on the River Shannon, to Dublin City, Ireland.

Commenced in mid-2001, the purpose of this Study was to carry out a strategic analysis of the existing foul and surface water systems in the Dublin City Region. The Study can be accessed and downloaded at: http://www.dublincity.ie/WaterWasteEnvironment/WasteWater/Drainage/GreaterDublinStrategicDrainageStudy/Pages/RegionalDrainagePolicies-OverallPolicyDocument.aspx
A Methodology to Investigate Adaption for Zero Carbon Living

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Abstract

There are very few studies that have investigated private homeowner and social housing tenants’ awareness and perceptions of what it means to live sustainably and no known studies that have looked at perceptions and awareness of the adaptation required (behavioural change) to live in a sustainable or zero carbon home. This research is timely with increased demand for energy reduction through the emphasis of zero carbon, including new legislation and in particular the introduction of the UK’s Code for Sustainable Homes. Indeed in 2009 the UK’s Housing Minister John Healey confirmed that the UK will be the first country in the world to require zero carbon homes as a matter of law from 2016. However the barriers and motivators surrounding environmentally responsible behaviour (ERB) required to fully adjust to living in a sustainable or zero carbon home, need to be investigated, as historically transitioning to unfamiliar living environments has required significant adjustment. Fien et al. (2008) identified three common assumptions made in programmes aiming to create ERB. Assumption one is that being privy to appropriate information will simply lead to ERB; assumption two is that if a person understands their personal contribution to climate change they will respond with ERB; and thirdly that individual behavioural change is superior to that of the collective. This paper outlines a methodological approach which has been developed to address these three assumptions, by engaging with homeowners and tenants to measure their conceptions and perceptions of what it means to live ‘sustainably’ and make recommendations towards successful adaptation to living in a zero carbon home.

Keywords: adaptation, environmentally responsible behaviour (ERB), housing, zero carbon
1. Introduction

1.1 Towards zero carbon

It is known that building contribute to almost half of the UK’s carbon emission. The role of the government is to reduce carbon emission by 60% by 2050 and to achieve this it is necessary to ensure all new housing is significantly more sustainable (Department for Communities and Local Government, 2008).

In July 2007 the Government’s ‘Building a Greener Future: Policy Statement’ announced that all new homes will be zero carbon from 2016. Following this commitment and a Policy Statement to consult further on the definition of zero carbon, in December 2008 the Government published ‘Definition of Zero Carbon Homes and Non-Domestic Buildings: Consultation’. This proposed an approach based on:

- high levels of energy efficiency in the fabric of the home;
- a minimum level of carbon reduction to be achieved onsite or through directly connected heat; and
- a list of allowable solutions for dealing with the remaining emissions (including from appliances).

To this end a Code for Sustainable Homes (CSH) was established. This is the National standard for the sustainable design and construction of new homes. The Code aims to reduce carbon emissions and create homes that are more sustainable. CSH measures the sustainability of a new home against nine categories of sustainable design, rating the ‘whole home’ as a complete package. CSH uses a one to six star rating system to communicate the overall sustainability performance of a new home. CSH sets minimum standards for energy and water use at each level CSH has replaced Ecohomes in Northern Ireland, England and Wales; but not in Scotland (Department for Communities and Local Government, 2008).

Table 1: Energy reduction requirements

<table>
<thead>
<tr>
<th>Date</th>
<th>2010</th>
<th>2013</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency Improvement of the dwelling compared to 2006 (Part L Building Regulations)</td>
<td>25%</td>
<td>44%</td>
<td>Zero carbon</td>
</tr>
<tr>
<td>Equivalent standard Within the code</td>
<td>Code level 3</td>
<td>Code level 4</td>
<td>Code level 6</td>
</tr>
</tbody>
</table>
The energy cuts proposed for buildings by CSH are ambitious (see table 1); and require new approaches to design and construction practice. However these alone are not sufficient. In addition to mitigation (action to reduce the impact of housing on the environment) there is a need for adaption; namely changing habits to reduce consumption also.

1.2 Designing for zero carbon

When designing and building new housing (and in particular when focusing on current carbon emission targets), business as usual is not an option. It is not only a case of reducing exiting consumption; it is also necessary to address the increasing energy demands that come from a larger population in more households, with higher expectations.

Before proposing an approach to reducing energy consumption in the home it is important to identify why recent building design hasn’t acted as a catalyst for change. Fundamental changes to the way housed are designed and built are required to meet the challenges set by the government for zero carbon homes in 2016. Indeed design is crucial to achieving zero carbon. The industry must create effective durable and adaptable buildings that meet or exceed energy performance now in order to be designing for zero carbon in five years time.

Appropriate design and technology alongside occupant engagement are necessary if zero carbon targets are to be reached. What is also necessary is ongoing research to learn from existing and new homes to ensure that they meet their design performance in use; and to assist occupants to live in them with optimum energy efficiency. Whatever approach is taken it is necessary to ensure that it does not worsen fuel poverty, reduce build quality or lessen user engagement. However it is undeniable that there is the need for immediate action on a scale that matches the enormity of the climate change challenge.

1.3 Reducing carbon emissions from existing buildings

UK homes alone account for around 27% of the UK’s carbon emissions, a major contributor to climate change (Department for Communities and Local Government, 2008). The Department for Communities and Local Government laid the foundations for greener housing when it launched CSH in 2007 in order to protect and enhance the environment whilst tackling climate change. CSH aims to minimise environmental damage from the construction process as well as revolutionising housing design in a way that encourages people to live more sustainably. However in addition to considering new build, there are 25 million existing domestic buildings in Britain, many of which are in need of significant refurbishment or replacement due to their energy inefficiently and general deterioration and inability to be adapted appropriately. Significant variations in the design and construction techniques used to build UK houses means that the energy efficiency of housing ranges widely.
Sustainable decision making is made difficult by the debate over retrofit versus new build. The majority of the UK’s aging housing stock was constructed with little regard for energy conservation; consequently there is significant potential for improvement. Key strategic decisions concern the rate at which this aging housing stock is replaced and which building should be targeted for demolition and replacement. Understandably complex social, economic and environmental issues must be balanced. Measuring energy use involves the use of embodied energy calculations. This is important when considering the fact that refurbishment to higher efficiency standards has around 10% of the carbon impact of a new build (Sustainable Development Council, 2006). There is a general consensus however that the impact of embodied energy in demolition and replacement can be outweighed by the energy saved in use for efficient buildings.

Whatever the conclusion both refurbishment and new build must achieve substantially higher energy savings than at present. There are significant challenges for both. It is unrealistic to assume that most buildings can be refurbished to the same energy standards as can be achieved with new build, which is why in many cases new build is considered to be the better option (Centre for Alternative Technology, 2007).

Space and water use account for most of the energy use in the homes. Indeed, energy use has consistently risen in the past 30 years and not as expected. Whist energy use for cooking has fallen, space heating has risen significantly due to an increase in central heating and raised expectation in comfort levels, although this has been moderated to an extent through improve insulation (roof & wall) and more efficient boilers. Lighting and appliance consumption continues to rise every year. Indeed the energy consumed in the use of domestic appliances (e.g. the average household now owns two and a half TVs and plasma screens use up to four times the energy of previous designs) has risen exponentially (Maley, 2006). Standby power is also a significant consumer of household energy with the Department for Environment, Food and Rural Affairs’ market transformation programme (2007) estimating that an appliance’s standby power can be calculated to be between five and 30 watts which accounts for between six and 10% of annual household demands (Department for Environment, Food and Rural Affairs, 2007).

All these issues must be addressed in order to develop adaptation strategies, yet there are very few studies that have investigated private homeowner and social housing tenants’ awareness and perceptions of what it means to live sustainably; and no known studies that have looked at perceptions and awareness of the adaptation required (behavioural change) to live in a sustainable or zero carbon home.

In this paper the authors present a methodology which has been developed to support the exploration and development of environmentally responsible behaviour (ERB) amongst home owners and social housing tenants. The intention of this methodology and the interventions suggested is to aid and support ERB alongside any technological interventions that may be employed to support and promote carbon reduction. This research is necessary if the UK Government’s pledge to become the first country in the World to require zero carbon homes as a matter of law from 2016 is to be met.
1.4 Environmentally responsible behaviour

Perceptions of climate change in the UK vary greatly. In a public attitude survey undertaken by Curry et al. (2005: 7), 28% of participants stated that ‘we will have to change our lifestyles to reduce energy consumption’, whereas 27% of respondents stated that ‘global warming is a problem but the UK won’t do anything about it’. Indeed 27% stated that ‘researchers will develop new technologies to solve the problem’, which means that a large number of those participating in the survey did not feel they had a responsibility to change their environmental behaviour, relying solely on centralised mitigation to address the problem.

Programmes which focus on empowering end users to take ownership of and reduce their impacts on climate change, must consider both how technology can be used to reduce carbon emissions; and the extent to which user behaviour must respond to technology to create durable change. Programmes face a twofold challenge of technical and human factors (Costanzo et al., 1986). An understanding that social factors and technology cannot be considered in isolation is paramount.

A central argument in the climate change debate is the understanding that transition requires changes to human action and behaviours (Moloney et al., 2009) and so behavioural change is seen as the only goal of consequence (Costanzo et al., 1986). Programmes attempting to create ERB must address: theories of persuasion; attitude change; the decision making process of the individual; and an understanding of the correspondence between attitudes and behaviours (Costanzo et al., 1986); as well as address issues of durability and the behavioural scope of interventions (Harland et al., 2004). A number of programmes which focus on the end user taking responsibility for changing their contribution to climate change have been suggested, however few agree on the most effective strategies for influencing the end user to develop ERB (Moloney et al., 2009).

1.4.1 Assumptions surrounding ERB

The barriers and motivators surrounding ERB, which are required to fully adjust to living in a sustainable or zero carbon home, need to be investigated as historically transitioning to unfamiliar living environments has required significant adjustment. Fien et al. (2008) identified three common assumptions made in programmes aiming to create ERB. These are outlined below.

1.4.2 Assumptions underpinning ERB programmes

The first assumption is the supposition that being privy to the right information will automatically result in an individual demonstrating ERB. However as argued by Moloney et al. (2009) information alone is unlikely to result in sustained behavioural change, although initially there might be some evidence of behavioural modification, this is not sustained in the long run.

The second assumption is based on the idea that if an individual or community were to understand how their personal and/or collective behaviour potentially contributes to climate change they would be more likely to adopt ERB. Moloney et al. (2009) dispute this assumption based on evidence that it
is impossible to predict how an individual or community may respond to information. Indeed contrary to empowering the individual/community, such an approach may result in disinterest, disempowerment, and scepticism or even fear (Finger, 1993; Australian Psychological Society, 2008). In addition, behaviours may by so engrained that modification needs more than just the provision of information if ERB is to become a habit or a social norm.

The final assumption implies that previous programmes demonstrate a preference for changing behaviours at an individual level as opposed to tackling communities whether social, political or economic/governance. As demonstrated by Moloney et al. (2009) this has proven to be an ineffectual approach if there is no understanding of the social norms and constructs which characterise society; fundamentals that need be considered and actively demonstrated if individuals and communities are to embrace change. Indeed, the World Wildlife Fund (2008) recommend that future programmes must address intrinsic values such as personal growth and community involvement at all levels.

1.4.3 Evaluation criteria for ERB programmes

Five key themes emerged from Moloney et al.’s 2009 review of behaviour change programmes and socio-technical approaches to understanding energy use and consumption, namely:

1. Framing behaviour and social practices;

2. Beyond barriers and constraints;

3. Approaches to agency and empowerment;

4. The need for systematic changes; and

5. Paths through learning and integration.

Based on these criteria, Moloney et al. (2009) made recommendations regarding future behaviour change intervention programmes which suggested that programmes must:

6. Map behaviours as a precursor to achieving behavioural change;

7. Consider technological interventions, the consumer/end user, and the relationship between them;

8. Study of motivations, values and self efficacy;

9. Take into account social norms and practices that underpin the behaviour of the individual or community; and

10. Include both top down and bottom up processes, encompassing stakeholders and end users.
In the next section, a methodology is described which has been developed to address each of the five recommendations made by Moloney et al. (2009) as outlined above, with the intention of presenting an approach to ERB which adds value to current programmes aimed at meeting the needs of sustainable living, in particular to ameliorate the Government’s approach to tackling zero carbon housing targets.

2. Approach

2.1 Decision support framework

In order to demonstrate how the proposed methodology captures the recommendations of the work undertaken by Moloney et al. (2009) a decision support framework has been developed. This approach is currently being adopted on a number of projects in order to facilitate lasting behaviour change in respect to ERB and housing occupancy (e.g. Hayles and Dean, 2010; McCullough et al., 2010).

2.2 Methodology

The first stage of the process is to acquire a ‘snap shot’ of the participants’ current awareness, perceptions and understanding of sustainability at a global, community and individual level. This involves asking questions which seek out information without informing or leading or coercing the participant to give what they might consider to be an expected response as opposed to their current understanding. Behaviour measures are also captured (Hayles and Dean, 2010). This allows the consultants to not only get a snap shot of current perceptions and awareness of sustainability at the different levels, but also to calculate on an individual and community level the ecological footprint of the participants as a baseline measure.

The structured approach is broken down into the following steps:

1. Participants are asked questions designed to gather information on their perceptions, awareness and understanding of global issues in a way that does not bias their responses towards ERB. These are captured by getting participants to rank key issues facing society today in order to establish how highly they prioritise sustainability issues such as climate change, the energy crisis and overpopulation, in relation to other current affair such as obesity and the credit crunch. Following on from this, participants are presented with a list of topics which all negatively impact to some extent or another on the environment, and again asked to rank these according to how important they are perceived to be. The final part of this stage of the process is to ask participants their present understanding of words and phrases used by the media to refer to environmental impacts such as biodiversity, one planet living, zero carbon and food miles.
2. Behavioural measures and frequencies are ascertained through in depth interviews with participants. This approach allows the consultants to develop a deeper understanding of all relevant aspects of participants’ day to day lives including their consumption habits, transport usage, recycling practices, home energy and water use. Using the data, consultants are then in a position to calculate the following ecological footprint domains: carbon footprint; food footprint; housing footprint; and goods and services footprint of each of the participants using the calculator provided online by Redefining Progress (2009).

3. The feedback part of the process takes many forms dependent on circumstance and learning styles of individual/group (Schmeck, 1988). Feedback is provided in the form of one or more interventions to promote ERB. These range from time i.e. giving the participants time to respond to self learning during the process, through to technological interventions such smart metering (e.g. Hayles and Dean, 2010). Focus groups, literature, media, online tools and support may also be made available to support behavioural change (e.g. McCullough et al., 2010). Interventions may take place in parallel or in series, again dependent on the nature of the participants. When interventions take place in parallel, participants are given a choice of behavioural support mechanisms from which they can select. Their selection may reflect their preferred learning style or they may choose to take advantage of all the support provided. When interventions are provide in series, the order in which they are offered is depended on the project and the decision framework adopted by the consultant that can either demonstrate an increase in complexity of the behavioural change support mechanism or in order of the financial cost of each intervention, or the time constraints of the project.

4. It is anticipated that there will be varying levels of positive behaviour change towards ERB as a direct result of the participants expose to one of more of the inventions described. This type of behaviour change is seen as empowering as it is self driven, and more likely to result in self efficacy, motivating further ERB. In the case of community driven projects be they domestic or community based, once the number of people demonstrating ERB crosses a threshold of critical mass, ERB may be considered the social norm, influencing those less motivated as they feel obliged to conform to social pressure (Bearden et al., 1989).

A similar process is applied to design teams and stakeholder groups. Whilst there is no need for the intervention stage of the process, feedback on their perceptions and awareness of ERB, end user behaviours and how to make connections between the two to improve the quality of design to further encourage and support ERB is undertaken.

Engaging all participants in effective and participatory problem solving gives an opportunity for individuals to develop their own solutions to ERB. It has been well documented that programmes which incorporate devices to feedback about performance to the participant increase the sense of both individual and collective value (Bandura, 1977). Feedback alongside social support is more likely to accomplish ERB and more importantly durable pro-environmental change (Harland et al., 2004). Kaplan and Kaplan (1989) rationalise this as human nature; an inherent desire to be a part of something rather than being incompetent or helpless.
Within the framework it is also recognised that both convenience and cost influence likeliness and
willingness to act; and must therefore be considered alongside the altruistic position of the participant.
The methodology allows a project to establish an equilibrium and find the balance between a reliance
solely on moral responsibility and the desire for economic gain which can result from more energy
efficient living (Kaplan, 2000; Winefield, 2005).

3. Conclusions and way forward

It has been stated that fundamental changes to the way houses are designed and built are required to
meet the challenges set by the government for zero carbon homes in 2016. However, if we do not
tackle people’s attitudes and begin to understand how they might adapt and adopt ERB, we will
neither reach nor sustain these targets. It is therefore imperative that ERB programmes are used in
conjunction with the prescribed changes to the design and construction of housing; to address both
mitigation and adaptation needs.

Previous ERB programmes have failed to deliver lasting results because they have not appropriately
supported individuals’ and communities’ (Costanzo et al., 1986). These programmes were based on
the three fundamental assumptions (Moloney et al., 2009) which the methodology presented in this
paper intends to address. The five distinct categories identified by Moloney et al. (2009) as a
framework to ensure programme success, namely: framing behaviour and social practices; beyond
barriers and constraints; approaches to agency and empowerment; the need for systematic changes;
and paths through learning and integration have also been addressed through the methodology. The
result is a structured framework, with built in flexibility to optimise ERB and sustained behaviours.

The next stage of the research is to assess the application of the methodology on a number of
concurrent projects to identify critical success factors.

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The Performance of Dwellings Specified by the UK Zero Carbon Homes Policy in Future Climate Conditions

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Abstract

The UK Zero Carbon Homes policy aims for all homes to be ‘zero carbon’ by 2016. The definition of a Zero Carbon Home for this policy will include a demanding energy efficiency backstop. This will require low thermal transmittances for the building envelope, low thermal bridging, low air permeability, and will favour designs that utilise solar gains. However, since ≈0.6°C of climate change has already occurred and further climate change is inevitable, these dwellings must be both low carbon and comfortable in a changing climate. Here, future weather data is generated from the climate change projections of the UK Climate Impacts Programme. Using this future weather data, dynamic thermal simulation is conducted on a Zero Carbon Home design. Shading and shuttering, window opening, and thermal mass are assessed for their potential to prevent unacceptable overheating. Further, the heating and cooling demand of the dwelling is assessed with current and future weather data. The results show that, under current climate conditions, unacceptable overheating can be prevented through the use of shading and shuttering, except in bedrooms where unacceptable overheating may still occur if window opening is limited. Therefore, where high levels of window opening are not possible, other strategies for ventilation must be explored. Under future climate conditions, unacceptable overheating becomes increasingly difficult to avoid, particularly night-time overheating. Therefore, the introduction of active cooling in UK homes may be inevitable in the future. However, low carbon home designs should strive to minimise any cooling demand through the methods discussed here and others.

Keywords: zero, carbon, homes, climate, change
1. Introduction

1.1 Background

In response to the issue of climate change the UK government has a policy that all new homes should be Zero Carbon Homes by 2016 (CLG, 2007). The final definition of a Zero Carbon Home for the purposes of this policy is under development. The definition will include a demanding energy efficiency standard. This is likely to a minimum space heating and cooling energy demand. The proposed levels are a maximum of 39 kWh/m²/year for mid-terraces and flats, and 46 kWh/m²/year for end-terrace, semi-detached and detached dwellings. The exact levels are expected to be confirmed in 2010 (ZCH, 2009).

In practice, this will mean that the 2016 Zero Carbon Homes will require low thermal transmittances (U-values) for construction elements, low thermal bridging, and low air permeability. Dwelling designs that utilise passive solar gains to further reduce space heating demand will be favoured. In addition, to achieve the Zero Carbon Homes standard, the dwellings will require low and zero carbon technologies to supply heat and/or power, and may use other ‘allowable solutions’ to offset any remaining emissions (for further details see CLG (2009)).

The primary aim of the Zero Carbon Homes policy is to reduce emissions from new dwellings as part of an effort to mitigate climate change. However, it is known that climate change has already occurred (≈0.6°C rise in global mean surface temperature over last century), and that further climate change is inevitable due to emissions to-date and some unavoidable future emissions (IPCC, 2007). The full extent of climate change experienced will be dependent on the global mitigation effort but any mitigation effort will still result in some degree of climate change. Therefore, new dwellings should be designed to best contribute to both the mitigation effort in, and adaptation to, the inevitably changing climate.

In order to assist design processes such as this, climate change projections have been developed for the UK by the UK Climate Impacts Programme (UKCIP). These projections give an indication of likely short term changes to our climate, and the possible long term changes that could occur if different global carbon emission pathways are followed. The UKCIP 2002 projections (Hulme et al., 2002) were integrated into a tool, CCWeathergen (Jentsch et al., 2008), such that climate change weather-data files could be generated for use in building thermal simulation. It is important that climate change projections such as these are applied to planned new buildings, such as those specified by the UK Zero Carbon Homes policy, so that the buildings can be future-proofed against the impacts of climate change.
1.2 Aim

This study aims to demonstrate the challenges faced in designing dwellings for the UK Zero Carbon Homes policy. The key challenge explored here is that of reducing current energy consumption and carbon emissions by reducing space heating demand, however, also ensuring that dwellings can adapt to, and remain low carbon in, a hotter future climate.

To this end, a case study building is employed, which is a low energy home design intended for use on a Zero Carbon Homes development. Using thermal simulation, the dwelling’s space heating energy demand is calculated and overheating analyses are conducted using both current and future weather data. The aim is then to assess whether overheating can be prevented in the dwelling both under current and future climate conditions. The following methods are assessed in terms of their ability to prevent overheating: shading and shuttering, ventilation from windows, and thermal mass. Further, if the stated methods cannot prevent overheating, it is the aim to determine to what extent active cooling will be required and the effect of this on the dwelling’s carbon emissions.

2. Method

2.1 Building and thermal simulation

The Zero Carbon Home design used in the thermal simulations of this study is shown in figure 1. It is a terrace of three 3-bed town-houses; a typical modern arrangement designed to give large floor areas on a minimal dwelling footprint. However, these dwellings have been designed to have increased passive solar gains through large south-facing windows, as a means to reduce space heating demand. The construction elements are specified to meet the energy efficiency standards of the UK Zero Carbon Homes policy – their thermal properties are shown in table 1.

Figure 1. Thermal simulation model of the case study building: a terrace of three 3-bed town-houses designed for increased passive solar gains.
Table 1: Dwelling construction elements and their physical properties: thermal transmittance (U-value) and solar transmittance (G-value).

<table>
<thead>
<tr>
<th>Construction</th>
<th>U-Value (W/m².K)</th>
<th>G-Value (BSEN410)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall: Render / Plywood / Cavity / Insulation / Plaster</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Ground Floor: Clay / Brick / Cast Concrete / Insulation / Screed</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Roof: Stone chippings / Felt / Plywood / Insulation / Cavity / Plaster(Dense)</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Internal Partitions: Plaster / cavity / Plaster</td>
<td>1.78</td>
<td></td>
</tr>
<tr>
<td>Intermediate Floors: Timber Flooring / Cavity / Plaster (Dense)</td>
<td>2.35</td>
<td></td>
</tr>
<tr>
<td>Unglazed external door</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>External glazing</td>
<td>0.80</td>
<td>0.64</td>
</tr>
</tbody>
</table>

The infiltration rate of the dwellings is defined as 0.087 air changes per hour (ach) – equivalent to an air permeability of 3.5 m³/m².hr@50Pa. An additional 0.5ach from mechanical ventilation was applied to all rooms. The internal gains from people, lighting and equipment in the different room types of the dwelling and their appropriate time profiles were derived from the National Calculation Method (NCM) activity database (available from http://www.ncm.bre.co.uk). An exception was that lighting gains were reduced to 4 W/m² when on in all rooms to account for low energy lighting. The high intermittent gains in kitchens and bathrooms are taken to be cancelled out by purging extract ventilation but neither is modelled.

The thermal simulations were conducted on the model using the ApacheSim component of the IES Virtual Environment. The results presented are for the central dwelling in the row of three. Space heating demand was calculated using a heating set-point of 19°C for all rooms between the hours of 0630-1000 and 1500-2300 in the months October to April, with a minimum temperature set-point of 12°C at all other times. Where active cooling is modelled it is to 26°C between 2100-0800 for bedrooms, 0630-1000 and 1500-2300 for all other rooms.

The overheating analyses focused on living spaces (‘lounge’ and ‘live’) and bedrooms (‘bedroom’) (see figure 1); occupied periods for these areas were taken as 0800-2100 and 2100-0800 respectively. Hence the total number of occupied hours in the tested range is 4745 and 4015 per annum respectively. CIBSE Guide A (2006) defines unacceptable overheating as greater than 1% of occupied hours over 28°C for living spaces and greater than 1% of occupied hours over 26°C for bedrooms.

In order to model adaptive behaviour to prevent overheating, window and door opening was included in the simulations. Windows are opened when the internal dry resultant temperature within the room reaches 21°C between May and September and 23°C at other times. The lower temperature is to account for human adaptation in summer. Windows only open when external temperature is less than indoor air temperature. Of the multi-panel windows shown in figure 1, two panels are openable in each, except on the upper floor where four panels are openable.
Internal doors are modelled as being open continuously to 15% of area; external doors remain closed at all times.

In order to model the effects of design choices and scenarios, alternative settings were modelled for: shading and shuttering, window opening, and thermal mass. These are summarised in table 2. The alternative settings for shading and shuttering and thermal mass investigate design choices. The alternative settings for window opening investigate two scenarios: one where window opening is unconstrained; the second where issues of noise and security limit window opening.

Table 2: Alternative settings for shading and shuttering, window opening, and thermal mass in the dwelling.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Code</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shading and shuttering</td>
<td>N</td>
<td>No Shading structures or shuttering (as shown in figure 1).</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>Shading structures added as shown below. Includes side-shading and louvres on ground floor and overhangs on upper floor. Shutters are modelled on the two foremost, south-facing windows. Shutters close in months May to September when direct solar radiation exceeds 100 W/m².</td>
</tr>
<tr>
<td>Window opening</td>
<td>LWO</td>
<td>Low window opening:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground floor window panels can open to 15% of area 0900-1600.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bedroom window panels can open to 15% of area 0800-2100.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other window panels can open to 15% of area at all times.</td>
</tr>
<tr>
<td></td>
<td>HWO</td>
<td>High window opening:  All window panels can open to 30% of area at all times.</td>
</tr>
<tr>
<td>Thermal mass</td>
<td>L</td>
<td>Lower: A single layer of lightweight plaster either side of the cavity in the internal partitions. Thermal capacity is 15 kJ/m² K.</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>Higher: A double layer of dense plaster either side of the cavity in the internal partitions. Thermal capacity is 32.5 kJ/m² K.</td>
</tr>
</tbody>
</table>
2.2 Weather data

For simulations in current climatic conditions the CIBSE 2005 Design Summer Year (DSY) weather file for Leeds was used. This weather file type represents a near-extreme year for high summer temperatures which can be used to assess a building design’s resilience to overheating (Ren et al., 2003).

In order to simulate future climatic conditions, future weather-data files were generated. This was achieved using the CCWeathergen tool (Jentsch et al., 2008). This tool allows climate change projections from UKCIP 2002 (Hulme et al., 2002) to be morphed with CIBSE weather-data to produce future weather files for 2020, 2050 and 2080. The UKCIP projections come from the Hadley Centre’s HadRM3 regional climate model, which has a resolution of 50km² and is embedded within the HadCM3 global climate model. The severity of climate change, particularly beyond 2050, is predicted to depend on future carbon emissions. Therefore, projections are available for four scenarios reflecting the warming associated with different carbon emission pathways.

The four carbon emission pathways and the resulting global warming scenarios are explained in chapter 3 of the UKCIP02 scientific report (Hulme et al., 2002). The climate science on which this is based is somewhat dated. However, whilst the carbon emissions pathways in the ‘high’ and ‘medium-high’ scenarios look unrealistically high, the predicted global mean surface temperature changes by end of century do not. The ‘medium-high’ scenario predicts around a 4°C increase in global mean surface temperature by 2100. This is consistent with projections that consider current emissions and the most up-to-date climate science (Anderson and Bows, 2008). Therefore, the ‘medium-high’ scenario is used here to generate CIBSE DSY future weather files for 2020 and 2050. In any case, all scenarios give similar temperature change up to 2050 before diverging markedly between 2050-2100.

The ‘morphing’ methodology used here to generate future weather data is the same as that used to generate the now commercially available CIBSE future weather files. However, the ‘morphing’ methodology may not be ideal when generating DSY-type weather files, as it may not accurately capture the effect of climate change on climatic extremes. As discussed by Jentsch et al (2008), an alternative method is to use climate models as the data source from which to stochastically generate future weather data. Some such data is available as an output from a project at the Climate Research Unit, University of East Anglia (BETWIXT, - ). Whilst there are currently practical difficulties in applying this data to building simulations, this method may ultimately be a more robust way to generate future weather data.

3. Results

The following are the results from thermal simulations, using the ApacheSim component of IES Virtual Environment, conducted on the Zero Carbon Home design shown in figure 1. Three variables: shading and shuttering, window opening, and thermal mass, were altered as shown in
table 2. All combinations of these variables were simulated and each combination was simulated using three weather data files: Leeds current DSY, Leeds Medium-High 2020 DSY, and Leeds Medium-High 2050 DSY.

Figure 2 shows the maximum average dry resultant temperature and the number of degree hours over 27°C for the whole dwelling. As is shown, both the maximum average temperature and number of degree hours over 27°C are significantly increased for dwellings with the same settings when the future weather files are used. For dwellings with same settings for shading and shuttering and window opening, the high thermal mass dwelling has a slightly lower maximum average temperature and has a lower, often markedly lower, number of degree hours over 27°C. In all cases, the application of shading, higher window opening, and higher thermal mass, separately or in combination, causes a decrease in maximum temperature and number of degree hours over 27°C.

Figure 3 shows the number of hours over 28°C in the ‘lounge’ and ‘live’ rooms of the dwelling. Also shown is the maximum acceptable hours >28°C for living areas under CIBSE Guide A. As is shown, the ‘live’ room has greater overheating in the non-shaded simulations than the ‘lounge’. This is because the ‘lounge’ already benefits from some shading due to an overhang. In the simulations with shading, overheating is very similar in the two rooms. Using the current DSY weather file, unacceptable overheating is prevented in all shaded dwellings, and in the unshaded dwelling with high window opening and high thermal mass. When future weather files are used fewer strategies prevent unacceptable overheating. When the 2050 future weather file is used, only those strategies with shading and high window opening prevent unacceptable overheating.

![Figure 2](image-url)

Figure 2. Maximum average dry resultant temperature and number of degree hours over 27°C in the Zero Carbon Home with different variables for shading and shuttering, window opening, and thermal mass (see table 2), and using different weather files.)
Figure 4 shows the number of hours over 26°C in the main, south-facing bedroom of the dwelling. Also shown is the maximum acceptable hours >26°C for bedrooms under CIBSE Guide A. When the current DSY weather file is used, figure 4 shows that unacceptable overheating is prevented only in those dwellings with high window opening. When future
weather files are used, only the dwelling with shading, high window opening and high thermal mass avoids unacceptable overheating, and this only with the 2020 DSY. Clearly, night-time overheating in bedrooms is the primary concern in the dwelling. It is interesting to note that higher thermal mass has variable effects on bedroom overheating. In some cases (no shading/low window opening), higher thermal mass increases overheating. This reflects the fact that thermal mass will not be effective unless heat absorbed in the day can be successfully purged at night.

It is clear that there is a risk of overheating in the Zero Carbon Home, particularly in a hotter future climate. The results show that under current climate conditions unacceptable overheating can be prevented in the living rooms through the use of shading and shuttering. However, in the bedroom unacceptable overheating may still occur if window opening is limited by noise and/or security issues. The increased temperatures projected due to climate change exacerbate overheating. Unacceptable overheating becomes increasingly difficult to avoid, particularly night-time overheating. None of the modelled dwellings avoided overheating in the bedroom using the 2050 weather file.

Should dwellings unacceptably overheat, either in pre-construction modelling or in post construction occupancy, then active cooling may be installed. Table 3 shows the heating demand of the dwelling with shading, low window opening, and low thermal mass, and the cooling demand if the dwelling was cooled to 26°C. As expected for a Zero Carbon Home design, the heating demand is very low (results not presented show that heating demand remains very similar between dwellings with the different settings for shading and thermal mass). The results show that as the climate warms the heating demand reduces slightly from its already very low level. However, cooling demand rises, albeit only to low levels when the cooling set-point is 26°C and cooling by natural ventilation remains in use.

Table 3. The heating and cooling demand of the Zero Carbon Home with shading and shuttering, low window opening, and low thermal mass, using different weather files.

<table>
<thead>
<tr>
<th>Dwelling</th>
<th>Climate file</th>
<th>Heating demand (kWh)</th>
<th>Cooling demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/LWO/L</td>
<td>Leeds current DSY</td>
<td>3281</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>Leeds M-H 2020 DSY</td>
<td>2902</td>
<td>282</td>
</tr>
<tr>
<td></td>
<td>Leeds M-H 2050 DSY</td>
<td>2525</td>
<td>431</td>
</tr>
</tbody>
</table>

4. Conclusions

The dwellings specified by the UK’s 2016 Zero Carbon Homes policy will require low thermal transmittance for construction elements, low thermal bridging, and low air permeability. In addition, dwelling designs that utilise passive solar gains to reduce heating demand will be favoured. However, these dwellings should be designed so as to be both low carbon and comfortable in a changing climate. Future weather data is now available and it is important to
apply this to models of planned new buildings, such as those specified by the UK Zero Carbon Homes policy.

Dynamic thermal simulations have been conducted here on a Zero Carbon Home design, using current weather data and future weather data for 2020 and 2050. Shading and shuttering, window opening, and thermal mass have been assessed for their potential to prevent unacceptable overheating. The results show that under current climate conditions unacceptable overheating can be prevented through the use of shading and shuttering, except in bedrooms, where unacceptable overheating may still occur if window opening is limited by noise and/or security issues. The increased temperatures projected due to climate change exacerbate overheating. Unacceptable overheating becomes increasingly difficult to avoid, particularly night-time overheating. None of the modelled dwellings avoided unacceptable overheating in the bedroom using the 2050 weather file.

It is clear that shading and shuttering are important to prevent overheating both now and in the future. In addition, high natural ventilation rates are important both currently, to prevent night-time overheating, and in the future to prevent overheating generally. Therefore, where it is felt that high levels of window opening will not be possible, due to issues of noise and/or security, other strategies for ventilation must be explored.

Finally, it has been shown that some form of cooling may be required in UK homes to maintain thermal comfort in future climate conditions. The cooling demands shown here are at low levels and therefore do not have serious implications for the dwelling’s carbon emissions. However, any cooling plant would incur a capital cost, and installed cooling may be used to maintain temperatures below the 26°C set-point modelled here. Therefore, low carbon home designs should strive to first minimise any cooling demand, through the methods discussed here and others, before resorting to active cooling.

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Tools of Backcasting Simulation to Predict Changes of Past Indoor Environment in Historic Building

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Abstract

Conservation activities are important and significant to protect the cultural resources and preserve the important heritage. However, future outdoor and indoor climate changes are predicted to give risk to the historical buildings. Due to these changes, historical buildings face the risk of deterioration of their fabric and content. The aim of this paper is to investigate the tools of backcasting simulation. Prior to this, method used will be the investigation of the historical weather data and the identification on the time when the building were or still without damage. Indoor and outdoor climate monitoring in real case studies will be carried out to represent these baseline data. Uncertainty and sensitivity analysis will be embedded to set up initial model. In conclusion, a methodology for simulation based forecasting can be developed to predict future risk in environmental changes.

Keywords: historical building, backcasting simulation, indoor/outdoor climate
1. Introduction

There will be changes in building demand in the near future as building profession may shift their focus from new construction to maintenance and refurbishment of existing buildings (Kohler, N., 2002) including historic buildings. Furthermore, it has become apparent that during these recent years and since the last decade, research on environmental condition in the historic buildings mainly in museum and archival building are in great demand (Pavlogeorgatos, 2003). On the other hand, there is an increase of research interest between the climate change effect and its impact to the cultural heritage. Some of the successful European researches concerning this area are Noah’s Ark, Engineering Historic Future, Climate Change and the Historic Environment, Special Project for Safeguarding Cultural Heritage and soon Climate for Culture and these are only few lists. Previous studies have shown that the older buildings may not withstand with the rapid changes of outdoor and indoor climate due to the different parameters of indoor climate condition and the requirements of people comfort condition. These changes will give risk to the built heritage by increasing or decreasing the occurrences of damage mechanism whether in the short term or long term timescale.

As a result, historic buildings will need proper conservation approach to safeguard a nation’s cultural resources and to preserve cultural heritage. To carry out efficient conservation and preservation activities, it is important to know the risk of deterioration and damages to the building fabric, its materials as well as interior moveable collections.

Furthermore, Sabbioni (2009) highlighted in a well known research the Noah’s Ark European project that there are still gaps to be filled in when it comes to the climate change impact on built heritage. Those gaps are (i) deterioration of historic buildings and archaeological landscapes studied on past or present term time scales and (ii) importance of novel climatic factors that affect buildings on a longer timescale. Therefore, this ongoing research is aimed to build up linkages between past and historical data on indoor environment and indoor climate performance in historical buildings through simulation based-backcasting. This is essential as it is hypothesized that the backcasting simulation can identify the past accepted indoor climate where during those time; there was no damage to the building. Further, with the exposure of short and long term environmental changes, indoor climate and building usage, the process of the existence of the deterioration can be studied. Then, a methodology for simulation based forecasting can be developed to predict the potential future risk to the old building.

1.1 Previous research

Research and experience have proved that the building envelope, components and interior of the older and historic building may not withstand with the changes of indoor environment took place in it. Here are some different approaches deals with some backcasting research in historic buildings in identifying risk of deterioration in old buildings.

Cassar and Taylor (2005) and Taylor (2005) did a research on natural ageing from past environment on book/paper based collection and predictions about future risk. The past environment study were done based on archival records and past weather data. By using simulation program, they did the environmental monitoring analysis and continue with analytical calculation to identify the rate of the
books deterioration. The results are used to predict the life expectancy of the books chemical-based collection through ageing and further possible preservation environment is suggested which include organizing, analyzing and reporting the suitable condition.

Blades et al (2006, 2007) on the other hand examine the hygrothermal environment in a historic building fabric and its impact due to the climate change. Effect on the current moisture balance is identified using heat, air and moisture model, thermal and energy model as well as climate model on three baselines period; 1970, 2020 and 2080. The wetting and drying projection are successfully identified where it shows that during 1970s to 2020s, there was and will be little effect of moisture on the wall while in 2080, external dry wall starts to appear, reduce potential for mould and alga growth in the internal wall.

Based on these researchers, it is concluded that past and historical condition of an old building can be investigated to understand the life cycle and the trend of the specific deterioration.

2. Aim

This ongoing research is aimed to build up linkages between the known past, and historical data on indoor environment and indoor climate performance in the building through simulation based-backcasting. This paper focuses on a hypothesis that the backcasting-based prediction simulation can identify the accepted historical indoor climate where during those time; there was no damage to the building and the collection.

2.1 Why need to backcast:

Jaco (2007) is defined backcasting as literally looking back from the future and it is the opposite of forecasting which looks from the present to the future. Furthermore, from the Noah’s Ark project, it is concluded that deterioration of historic buildings need to be studied on past or present term time scales and it is important to investigate the novel climatic factors that affect buildings on a longer timescale. Therefore, it is significant to first understand the very first impact of climate change on historic buildings in order to understand the life cycle of the specific objects or materials. This is where the backcast need to take place.

3. Methodology

Figure 1 is a flow chart, which shows the first prototype of backcasting simulation methodology. The following information will describe the stage in detail.

3.1 Building measurement

First, the building must have the real indoor climate measurement for at least one year. These measurements are used to evaluate the indoor climate of the room and latter will be used to calibrate the inputs used in computer model’s construction and validate the simulation’s results. The simulation
will be based on heat and moisture evaluation and will concentrate on the temperature and relative humidity measurements.

### 3.2 Set up of initial model

The model will be built up after suitable simulation program is selected. This research is concern with the hygrothermal and hygroscopic of the old buildings and objects. There exist few simulation models WUFI, Hambase, PHYSIBEL, Energy+, TRNSYS and FLUENT which usually used for simulating water and temperature distribution. In this ongoing research, assessments of the indoor climate especially on the room temperature and relative humidity are necessary to analyze the causes and impacts of climate change to this building. A simulation method based on heat, air and moisture movement is used with HAMBase program. Hambase simulation program has been chosen after considering its usability in other research done on old buildings. Hambase is specifically designed for the heat and vapour flows in a building where indoor temperature, indoor air humidity and energy use can be simulated (Wit, 2009a). However, often the case that its applicability to existent historic buildings with often unknown constructions and material properties. But, the Hambase has successfully proven in several research projects on indoor climate in old buildings. The hygric indoor climate can be evaluated as the main results of this initial model. Further, the moisture condition of the indoor climate can be used as methods for understanding and codifying the effects of ageing of old building.
Figure 1: Implementation of the proposed simulation based-backcasting methodology

3.2.1 Building information

Input such as the external climate data, building size, shape, construction materials, orientation, glazing system data and profiles for internal sources, ventilation and cooling/heating system are
3.2.2 Outdoor weather data

3.2.2.1 Finding and investigating weather data

- Historical weather data

The availability of a lengthy historical record in consistent time period can only be found in UK under the database of HadCET (Historical Central England Temperature Data). Together with Hadley Model, the output can be estimated for the period 1100–2100 CE (Brimblecombe, P., 2008). So, to attempt similar research in the other parts of Europe would be of interest. So far, apart from UK, the Netherland also has similar database called Ancient Klimatology Data, thanks to the Royal Netherland Meteorological Institute (KNMI).

The complete overall ancient climate database which can be found from the KNMI official website is recorded based on a complete integration of the synoptic meteorology after 1847 and climatologically networks since the first observation from 1612 to 1615 (Geurts and Engelen, 1983). Then, on June 1981 research on historical instrumental observation of the weather data officially started at the KNMI and consequently the calculation were used to process the historical readings of temperature (Engelen and Geurts, 1983).

At KNMI, the database of the ancient climatology data for Utrecht can be obtained for the year of 1881 until 1896. It is identified that these non-instrumental data are not completely recorded or measured. Figures 5 and 6 below show the distribution of outdoor temperature and relative humidity of Utrecht province in January, 1881. During those periods, the observation of a complete meteorological data were tabulated only in 7 different time scales; 200, 600, 800, 1400, 1800, 2200 and 2400. However, for the correction and conversion of the outdoor temperatures and relative humidity, they were only recorded during 4 time scale of 600, 800, 1400 and 2200. Figures 5 and 6 represent the incomplete distribution and missing information of the outdoor temperatures and relative humidity within these time scale in January 1981. However, these distribution patterns are only applied for the ancient climatology of Utrecht for the years of 1881 until 1890. For the year of 1891 to 1896, the meteorological data were tabulated in 8 different time scales; 200, 500, 800, 1400, 1800, 2200, 2400 and 2600.
2200 and 2400. For the outdoor temperature and relative humidity, the data were recorded only in 3 time scale; 800, 1400, 2200.

Figure 3: The original distribution of historical outdoor temperature and relative humidity in January, 1881 obtained from KNMI database

To make a simulation exercise over a year, it is a normal practice where the climate files need to be in hourly values for the whole one year period. Based on the above explanations, it is questionable that the backcasting simulation can be carried out to investigate the indoor climate of the Grand Salon during those periods. Therefore, those ancient climatology data need to be interpolated to hourly data for each year. Furthermore, to be consistent with the availability of the recorded data, it is necessary to choose the data within the same time scales. So, the interpolations of the ancient climatology data were done based on the same 3 time scale throughout 1881 to 1896; 800, 1400 and 2200.

The interpolation will be calculated based on the hourly data which are available from the existing hourly climate data from the year 1971 to 2005 (recent past files). On the other hand, the available ancient climatology data for the years of 1881 to 1896 (ancient files) were formatted in excel files before they were converted into .dat files, where latter they will be used in the MATLAB platform. Please keep in mind that all these ancient files will be saved in yearly basis. In general, MATLAB interpolation function will balance the smoothness of the missing data in the ancient files with the recent past files. As mentioned previously, the data in the ancient files are based on 3 time scales and the interpolation will estimate the values that lie between these known data points and to match them with the unknown missing data from the recent past files. However, it is fortunate that the ancient files from the KNMI have a meteorological data set that involves wind directions, wind pressure 0.1 kgf/m², temperature in 0.1 degree Celsius, daily precipitation, surface air pressure in 0.1 mm column of mercury, cloud cover in tenths and relative atmospheric humidity in percents. Therefore, it can be said that these ancient files are good enough to be the basis of the interpolation due to the reasonable data provided.

To interpolate the temperature data in between missing hours, with the function of interpl (xp, yp, xpi) where xp = the hour, yp is the temperature given at those hours and the xpi are the interpolated temperature. The same calculation will be applied for the interpolation of relative humidity but references were made from the saturated vapour pressure. The solar radiation interpolation on the other hand will be based on the calculated value of the cloud covered in tenth. First, the data will use the given cloud cover value in the selected historical weather data. The cloud cover value must be available for everyday, but also at the same frequencies of 3 times of measurement per day. Then, this value will be referred to the hourly cloud cover measurement from the recent past climate files.
whichever available. For example, 1 January 1881, the cloud cover was available at 800 and the value was 5. So, in the weather file of 1971 to 2005, also in 1 January, the data will find the same value of the cloud cover maybe at the same time, or one hour earlier, or 1 hour later whichever suitable but with the same value of cloud cover as in ancient climate files. From the chosen time, it is assumed that the ratio of the solar radiation will also be the same so then this value will be used in the historical weather file. However, if there are two values found in the different years, the solar radiation will be interpolated by using the half part of the earlier year, the other half part from the latter year and the average value of the overlapping period between those two years.

By having interpolated temperature, relative humidity, cloud cover and solar radiation, finally a complete hourly historical weather data for the year of 1881 to 1896 are successfully calculated.

- **Recent past, current and future weather data**

Current and recent past weather data are always available directly from the KNMI (Royal Netherland Meteorological Institute) official website. Future climate data is available from the Hadley model called HadCM3. The data can be extracted from the appropriate HadCM3 model grid cell from the present to 2099. As this paper will only concentrate on the backcasting simulation, further elaboration on future climate data and HadCM3 will not be discussed.

### 3.3 Comparison with real measured data and simulation

Comparison with real measured data is essential in part of setting up the initial historical properties of simulation model. In constructing this initial model, the baseline conditions were taken from the one year measurement done in 2004. An ongoing working model is shown as in Figure 4 below. The measured and simulated indoor temperatures are compared with a reference to the outdoor temperature. It can be concluded that there is still good sense in its pattern of temperature distribution and fluctuation especially from April to September. Investigation is still being carried out for the months of January to March on their significant disagreement. In summary, the disagreement is found to be only to the minimum at -1.8°C and maximum at 3.2°C. However, not in Figure 5 where it shows that the comparison in relative humidity is not really acceptable. Therefore, it is essential that this working model needs a lot more refinement as this is only preliminary results used for producing this paper.
3.4 Simulation based backcasting

Research on historic buildings and collection requires all data which are time sensitive presenting historical, present and future time scale with very different time constant. Through simulations different period can be linked. In order to study the impact of climate change on the built environment, the use of building simulation techniques together with forecast weather data are often necessary. Normally, building performance simulation is a tool which is used to support the designers of modern buildings, newly built or reconstructed, and their building systems. It can be expected that this tool is also capable to predict risks related to changes of natural indoor environment of historical buildings. This assumption is feasible only if an appropriate methodology would be developed to ensure that modeling and simulation is properly used in this new context.
Simulation based backcasting will deal with many unknown conditions which is explained further in uncertainties and sensitivity analysis. Predictions are required for the information which is not known precisely but with proper and concrete evidence. Together with complete building information and external historical, recent past, current and future climate data, correct inputs can give good results to predict the indoor climate of the building. However, monitored indoor climate parameters especially in temperature and relative humidity need to be carried out for a lengthy of time as minimum as one year. This data is crucial in order to calibrate and compare the simulation model of a historic input data from this baseline data.

This ongoing research will later use the computer model – which will be successfully calibrated and validated with real measurement – in backcasting simulation – with inputs from the historical weather data and past indoor environment of the selected historical building.

### 3.5 Uncertainty and sensitivity analysis

Hopfe (2009); uncertainty and sensitivity analysis are part and parcel of many ongoing research activities. In the design stage, uncertainty and sensitivity analysis will provide information about the reliability of the overall design. It is also concluded that uncertainty and sensitivity analysis are most commonly used to optimize the design process in the early stage. In building performance simulation during the design stage, uncertainty parameters are divided into physical properties, design adaptations and scenario condition while the sensitivity is the most influential parameters relating to one performance aspect of uncertainties where they are used for decision support and design optimization (Hopfe, ibid).

However, in a process where old buildings are the main subjects there is no more design stage as the buildings were already built and designed. As reported in Hopfe (ibid), Fenton (2006) agreed that uncertainties may derive from unquantifiable information, incomplete information and unobtainable information. One can agree that gathering information of historical buildings such as plans, buildings materials and specification can be obtained through archive and documentation research. Therefore, the uncertainties in terms of physical and design parameters would not be the most critical but can be difficult to obtain. However, other than physical and design uncertainties, uncertainties in scenario condition is very much related when considering research on climate, past, present and future. Scenario conditions are applied in the sense that they can change during the building life time. It is divided into internal which are related to the building operation or external scenario uncertainties which are caused by uncertainty in weather data and climate change.

It is a future challenge considering the scenario uncertainties that the impact of future climate scenarios would be beneficial to predict the future performance (Hopfe, ibid) of old buildings. Therefore it is assumed that considering the physical properties and building design and in the past can be investigated, search and obtained, uncertainty in scenario condition can be the most important part in this research to simulate the past performance of the old buildings using the simulation based-backcasting considering the environmental changes external and internal throughout the building life time.
Where this ongoing research is of concern with an old building, it will link its past changes in environmental conditions to object deterioration. In internal scenario conditions, information will be collected through environmental history, building information, records and archival documentation as well as oral evidence. For the external scenario conditions, past weather data will be done by the collection of ancient climate database from the Royal Meteorological Institute, estimation based on earliest literature, corrections, extraction and calibration against the existing database. Uncertainties in historical climate records constrain our understanding of natural variability of climate, but estimation of these uncertainties enables us to place recent climate events and extremes into a realistic historical perspective (Parker, 2009).

4. Conclusion

It can be said that the interpolation of data in MATLAB is a common approach. However, in this research, its usability to construct a complete one year hourly data for historical weather files is exceptional. Researches done by Brimblecombe (2008, 2009) have proven that past weather data can be estimated for the period of 1100 – 2100 CE. However, these data which are obtained from the Central England Temperature Record (CETR) and the Hadley Model climate data still remain to be cautious (Brimblecombe, 2008) as estimations were made based on earliest literature with the combination of several corrections for urban heat island, extraction from HadCM3 model and calibration against the CETR records. Based on his arguments, it is undeniable that this historical weather data constructed from interpolation in MATLAB is also open to discussion. But, yet it still can be a good basis for the preliminary backcasting simulation used in this research.

It is hoped that from the backcasting simulation, it will lead to an understanding of the likely accepted indoor environment in the past where at that moment, deterioration of the old building and the collection were predicted mainly on its natural ageing. As time flies, changes in outdoor and indoor climate due to climate change produces more agents to contribute short and long term risk which further worsen the deterioration process. Therefore, further investigation will be carried out to build up a better methodology for backcasting simulation and to predict past accepted indoor environment. Identification on the most important agent of deterioration due to climate change starting from the early stage (which is from the past) can help to mitigate and reduce the risk of predicted damage process in the future. Further the potential adaptation strategies can be proposed for future safeguarding purposes on the selected objects.

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A New Strategy for Mitigation of CO₂ Emissions by Reducing the Cement Consumption of Ordinary Concretes

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Abstract

Cement is one of the most important materials produced worldwide. In 2005, total annual production was over 2x10⁹ tons, which makes cement responsible for around 6% of global CO₂ emissions. This share has grown steadily over the last 80 years. Commonly used strategies to mitigate emissions are related to (a) energy efficiency in kilns; (b) the use of alternative fuels; and (c) replacing clinker with wastes or limestone filler. Recent studies have shown that the potential for reducing CO₂ emissions of all these strategies combined is around 30%. However, the production of cement is expected to increase 2.5 times over the next 40 years and, unless new mitigation strategies are developed, CO₂ emissions from the cement industry will continue to increase. This paper proposes to change the focus from cement production optimization to the optimization of its supply chain by placing emphasis on the concrete production industry, which is responsible for most of the cement consumption. Recent studies have shown that the minimum cement content in concretes established in most of the standards has no technical justification, even from a durability point of view. Using a bibliographical survey, this paper discuss the technical possibilities and limits of reducing cement content in concrete, based on literature and published data. The main conclusion is that there is a potential to reduce the average cement content in concrete making it possible to increase concrete production without increasing or even decreasing the production of cement and subsequently CO₂ generation. The main technical and political challenges facing this goal are analyzed and potential solutions for each one are discussed.

Keywords: concrete, cement, global warming, CO₂, sustainability.
1. Introduction

Nowadays, concrete is the world’s most consumed material. Cement accounts for 8 to 15% of concrete mass, but is responsible for more than 80% of the impact on global warming (Vares; Hakkinen, 1998). Worldwide, the production of cement reached more than $2 \times 10^9$ tons in the year 2005, which resulted in almost $2 \times 10^9$ tons of CO$_2$ released into the atmosphere (WBCSD, 2007).

The tendency shows an increase in the production of cement to more than $5 \times 10^9$ tons/year by 2050. This is mainly due to an increase in demand among developing countries, resulting in almost $5 \times 10^9$ tons/year of CO$_2$ related emissions (WBCSD, 2007). Although there are tremendous efforts to decrease emissions coming from the industrial cement production process, a 30% reduction in emissions is the maximum possible even when including the most common strategies – clinker substitution by mineral admixtures, improvement of kiln efficiency and the use of alternative and renewable fuels – implemented and developed by cement producers (Humphreys; Mahasenan, 2002).

It is not difficult to realize that the efforts of cement producers alone will not be enough to reach the levels of CO$_2$ emissions proposed by global warming studies and meetings, such as Kyoto Protocol, Stern Review (OCC, 2005) or IPCC Report (Bernstein et al, 2006), which take into account the need to decrease emissions below levels prior to the year 1990. Because of this, new strategies are required. In this way, it is necessary to develop further studies which can lead to strategies that increase cement use efficiency other than those used in cement production.

This paper proposes new environmental indexes for assessing cement use efficiency in concrete mixtures and evaluates how these indexes could help to understand the potential of CO$_2$ mitigation by disseminating the most efficient strategies for cement use optimization found in bibliographic data.

2. Methodology: measuring cement use efficiency

Cement use efficiency in concrete mixtures is strictly linked to global warming issues due to the fact that each ton of clinker – the main product of cement – emits from 820 to 1150 kg of CO$_2$, Table 1, which shows CO$_2$ emissions related to clinker production taken from data available in literature. Differences of almost 40% in the data found are related to production methods (wet or dry, and other variations mainly in kilns) and to the type of fuel used. For simplification an average value of around 1 ton of CO$_2$ emitted from each ton of clinker was assumed. So, the higher the clinker content in concrete, the more CO$_2$ emissions are related.
Table 1: Bibliographic data – CO₂ emissions related to clinker production

<table>
<thead>
<tr>
<th>Author</th>
<th>kg CO₂ per ton of clinker produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamamoto et al (1997)</td>
<td>824.25 to 1151.7</td>
</tr>
<tr>
<td>CEMBUREAU (1999)</td>
<td>1037.5</td>
</tr>
<tr>
<td>Gartner (2004)</td>
<td>859</td>
</tr>
<tr>
<td>Josa et al (2004)</td>
<td>821.1 to 900</td>
</tr>
<tr>
<td>USGS (2005)</td>
<td>960</td>
</tr>
<tr>
<td>IEA (2006)</td>
<td>913 to 1125</td>
</tr>
<tr>
<td>Damtoft et al (2008)</td>
<td>840 to 1150</td>
</tr>
</tbody>
</table>

The eco-efficiency of concrete must be measured in terms of CO₂ emitted. This assessment should not take into account simply how much CO₂ is emitted per m³ of concrete, because concretes have different performances and a concrete with a better performance and the same amount of CO₂ emissions as a concrete with a lower performance is comparatively more efficient. The same thing is valid for two concretes with the same performance and different CO₂ emissions: to deliver the same work, the more efficient concrete is the one with lower CO₂ emissions.

This concept is embedded in the Life Cycle Analysis (LCA) approach and was very useful in the creation of the first index for assessing cement efficiency in concrete: the CO₂ intensity (CI). This is measured by a simple division of the total CO₂ emissions from clinker contained in a concrete mixture, in kg·m⁻³, by the total compressive strength of the concrete, in MPa, as shown in Equation 1:

\[ CI = \frac{c}{s} \] (1)

where \( c \) is the total CO₂ emission (kg·m⁻³) generated by the production and transportation of all concrete materials. The calculation of this indicator depends on the availability of life cycle inventory data about all concrete constituents, mainly binders. In this work only the emissions from the production of binders were considered. \( s \) is the mechanical strength of concrete at any given age. In most cases \( s \) will be the compressive strength (MPa) at 28 days, but the selection depends on the application for which the concrete is designed.

This index presents a relation between concrete’s environmental impact (amount of CO₂ emissions, in kg·m⁻³) and performance – described here as the compressive strength, in MPa, which is the most important parameter used in commercial ready-mix concretes. So, it is possible to quickly and objectively assess the eco-efficiency of different concretes. The higher the CI, the greater the quantity of CO₂ emitted for each MPa provided, and the lower the eco-efficiency.

But clinker is not the only binder used in concrete. Some industrial wastes such as blast-furnace slag (from the steel industry), fly ash (from coal plants) and silica fume, are also used as binders in the production of concrete. These were considered to have zero emissions in terms of CO₂ emissions for measuring the CI due to the fact that they are waste from other industries and the CO₂ emitted during
their production is allocated in environmental impacts of the main products. But is necessary to remember that impacts related to these main products and their wastes are, many times, applicable to global warming. Steel, for example, can emit more than 1 ton of CO₂ per ton of produced material (Yamamoto et al., 1997; Gartner, 2004).

Summarizing, Table 2 shows emissions considered in CI calculus:

Table 2: Emissions considered in CI calculus for each of the main binders

<table>
<thead>
<tr>
<th>Binder</th>
<th>kg CO₂ per kg of binder produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinker</td>
<td>1</td>
</tr>
<tr>
<td>Fly ash</td>
<td>0</td>
</tr>
<tr>
<td>Blast-furnace slag</td>
<td>0</td>
</tr>
<tr>
<td>Silica fume</td>
<td>0</td>
</tr>
</tbody>
</table>

To mix concretes that reach very low CI values – which could imply a good concrete according to global warming concerns – it is not necessary to have a good mixture process. The mixer only needs to use low clinker content and compensate the lack of clinker with binders as zero CO₂ allocated emissions, such as slag or fly ash. The strategy of replacing clinker is many times used by some works that try to make “greener” concretes by using recycled waste, and this is even a strategy cited in LEED certification.

However, it is necessary to realize that this strategy, in spite of being environmentally sound, can hide some problems. Recycled wastes – such as fly ashes and blast-furnace slag – used as binder are not available on a large scale, or, at least, on a scale compatible with the expected growth in cement production. Humphreys; Mahasenan (2002) calculated that the maximum increase in clinker replacement by mineral admixtures will reach 12% in next 30 years, while cement production is expected to double in the same period, showing that CO₂ emissions from cement production will increase even if the entire world production of these wastes were used in concrete mixtures. It is also possible to imagine that, if all concrete producers start to replace clinker with these wastes, they will not be able to supply the total demand. Moreover, these approaches do not take into account the fact that steel production and thermo electrical plants are big polluters in terms of CO₂.

A second environmental index to measure cement use efficiency in concrete mixtures is proposed: **Binder Intensity (BI)**, which is the factor of the concrete’s total binder consumption, in kg·m⁻³, used to deliver each concrete compressive strength unit, in MPa. The calculus is in Equation 2:

\[ BI = \frac{b}{s} \]  

(2)

where \( b \) is the total consumption of binder materials (kg·m⁻³).
This index, expressed in kg·m⁻³·Mpa⁻¹ such as the CI, allows the analysis of total binder quantity needed to deliver each MPa of strength. The higher the BI, the higher the binder content needed and, consequently, the lower the concrete eco-efficiency.

In order to test the capacity of BI and CI indicators in measuring and evaluating concrete eco-efficiency and to develop a benchmark, a survey based on literature data was performed. A total of 156 papers published between 1988 and 2009 were analyzed. Two different sets of papers were tested. The first one was composed of 59 Brazilian papers, the majority published in the Brazilian Concrete Institute (IBRACON) yearly conference proceedings. The second set consisted of 97 papers from 28 countries, published in the Cement and Concrete Research and ACI Materials Journal. Selected papers presented 28 days compressive strength results and a clear description of the binder composition. A database with 1585 registers was built. The influence of sample geometry in compressive strength was corrected to the equivalent cylindrical sample (10x20cm) using models from Neville (1995), Mansur; Islam (2002) or Yi; Yang; Choi (2006).

When the binders were incorporated into the cement (a common practice in Brazil), the cements were separated into clinker, fly ash, blast-furnace slag, silica fume and other binder types. The average value of mineral admixtures of each cement type was used. This was intended to allow an estimated calculus of CO₂ emitted by the concrete mix.

3. Results and discussion: literature benchmark

This item shows the benchmark originated from the bibliographical survey. All results discussed are part of a paper which has already been submitted to Cement and Concrete Composites magazine by authors 1 and 3 (Damineli et al, 2010).

3.1 Binder Intensity (BI)

Figure 1 presents BI results from the benchmark versus compressive strength.

![Image](3.png)

Figure 1: BI versus compressive strength from a) Brazilian data; b) international data.
Figure 1 shows the same tendency for Brazilian (Figure 1.a) and international (Figure 1.b) data: high dispersion of BI for low strength concretes, and lower dispersion for high strength concretes. This suggests that, on the average, high strength concretes have higher eco-efficiency in terms of binder consumption – they use less binder to deliver each resistance unit, in MPa. The same Figure shows that a minimum BI of 4.3 kg·m⁻³·Mpa⁻¹ was the lowest tendency found in the benchmark – but this value occurred only for concretes with resistance above 50 MPa. This value can suggest the best eco-efficiency level possible in current concrete mixtures, at least in academic papers, with feasible possibilities to be diffused to market quickly.

For resistances under 50 MPa, it is very interesting to note that the minimum BI follows the line of total binder consumption of 250 kg·m⁻³, for Brazilian and international data. It is probably not a coincidence that the main world concrete mix standards determine the minimum cement content always near 250 kg·m⁻³, as can be seen, for instance, in ABNT (2006) or Grube; Kerkhoff (2004). So the authors believe that concretes with resistance lower than 50 MPa are, in general, less eco-efficient because of standards restrictions, which incite mixers to use at least this cement content for low resistance concretes even if this is not necessary.

Here, it is important to mention that some well-known concrete authors do not agree that a minimum cement content is necessary. Wassermann; Katz; Bentur (2009) published a work which shows that concrete durability does not increase linearly with an increase of cement content; on the contrary, durability parameters commonly increase when cement content is decreased. Concurring, Mehta (2009) affirmed that concrete sustainability depends on 3 related actions to decrease CO₂ emissions: 1) concrete volume reduction; 2) increase of clinker replacement; and 3) cement content reduction in concrete mixtures. Clinker replacement also increases concrete durability.

Because these conclusions are based on experimental data, Wassermann; Katz; Bentur (2009) believe that standards concerning minimum cement content in concrete should be revised, an opinion supported by the authors of this paper. This is a fundamental strategy for allowing the decrease of BI for concretes with less than 50 MPa, which is very important due to the fact that these concretes are the most widely used in current market practice. A BI of 5 or something near that could be feasible even for low strength concretes.

But a complete analysis about the eco-efficiency of concrete design must be transferred to the market, and not reserved only for literature research assessment.

In order to make a superficial evaluation of the market’s role in concrete eco-efficiency, one Brazilian ready-mix concrete producer was also consulted. As available data did not include cement type or binder description, only total binder content, only the BI index was measured. BI values varying from 9 to 11 kg·m⁻³·MPa⁻¹ were found, with an average around 10 for concretes between 20 and 40 MPa – the most commonly found in the market.

In spite of this data seems to confirm those found in literature (higher BI for lower resistance concretes), this was only a quick research and needs confirmation by an international market benchmark. Thus, the real importance of this superficial data is the fact that, again, the minimum
cement content seems to restrict the lowest BI values. There was hope that lower values of BI would be found in the market’s ready-mix concretes, which was not the case. On the other hand, this can indicates that there is a high potential to decrease BI from commercial concretes.

The cement optimization potential is also high when taking into account indigenous concrete practices: another quick research based in Brazilian manual for making “do it yourself” concrete appoints that these can reach BI above 17 if the best dosage parameters indicated are followed. In this case, the potential for decreasing CO₂ emissions from the cement supply chain would be much higher.

### 3.2 CO₂ Intensity (CI)

CI data calculated from benchmark are shown in Figure 2.

![Figure 2: CI versus compressive strength from a) Brazilian data; b) international data.](image)

Figure 2 shows that CI has the same tendency as BI: the higher the concrete’s compressive strength, the lower the values and the dispersion of CI results, and consequently the higher the eco-efficiency.

However, minimum CI reached less than 2 kg·m⁻³·Mpa⁻¹, a value much lower than the 5 kg·m⁻³·Mpa⁻¹ found for BI. This happens because some binders are considered as having zero emissions, so the more these types of binders are employed, the less clinker is consumed and fewer CO₂ emissions occur.

### 3.3 CI x BI – clinker replacement versus mixture improvement

Figures 1 and 2 show that some concretes have low CI for every compressive strength, which is encouraging, but may lead to an equivocal analysis about the use of mineral admixtures. It is possible to design a concrete with high BI but low CI, which is most common for low strength concretes considering the data observed in Figures 1 and 2: on the average, low strength concretes have higher
BI but not higher CI values when compared with higher strength concretes. Therefore, an eco-efficient concrete, in terms of CO₂ emissions, can be produced by using a lot of binders derived from wastes – such as fly ash and blast-furnace slag –, which can be a problem because there are not enough admixtures available to supply the world demand for concrete. Generation of these wastes is expected to grow at a lower speed than cement and concrete production increases, as cited by Humphreys; Mahasenan (2002) and presented above. In this case, concrete would not be produced more with admixtures in a near future, or, at least, the optimum replacement factor for global warming mitigation could not be expanded for all world concrete. Complementing the discussion on the availability of wastes, Müller; Harnisch (2008) show that in the last 5 years cement production increased 22% while clinker increased 20% – the difference is related to the increase in clinker replacement. The small difference in values indicates that there is a trend for CO₂ related emissions to continue to increase since clinker production is still increasing.

Even if wastes were available on an infinite scale, it is important to show that design parameters would not allow them to be used in a positive way. Müller; Harnisch (2008) showed that the average clinker factor from the Brazilian cement industry was around 0.65 in 2006, maybe the lowest in the world and that indicates a reduction in emissions related to cement. But, as can be observed in Figures 1 and 2, Brazilian and international data performances are quite similar. So, even with a lower clinker factor – or higher clinker replacement – Brazilian concretes are not significantly more eco-efficient than international ones, neither in BI and CI. This implies that clinker replacement alone does not guarantee concrete eco-efficiency. The eco-performance needs to be related to a precise concrete design which can provide rational binder consumption, with gains in terms of global warming emissions. So, a design parameters analysis is necessary in the research for eco-efficient concrete.

4. Towards a sustainable cement supply chain

Considering the data and discussions presented above, it is clear that a more eco-efficient concrete chain is possible in the not too distant future. The potential for decreasing CO₂ emissions by improving concrete design parameters seems to exist and was confirmed by the data evaluated. However, international collaboration is the key element for its success due to the high technical and political implications, and requires cooperation and management from important scientific research committees, institutes, organizations and communities. The challenges of developing more eco-efficient concretes necessarily raise questions such as: what must be done in order to decrease the consumption of cement? How are technical and political challenges embedded? Can a roadmap for a more sustainable concrete be established?

Initially, it is necessary to assure that the reduction of cement consumption is feasible from a technical point of view. To do this a more complete international benchmark is mandatory, including concise market data obtained from ready-mix concrete producers. With this benchmark well-established, it would be possible to estimate the real potential of CO₂ emissions reduction by strategy and the lowest possible cement consumption.

After confirming technical feasibility, concretes with the embedded concept could be produced in laboratory scale, while all available knowledge should be employed to reach the goal. Moreover,
some technical concrete parameters such as durability, fire resistance and impact strength, among others, would need to be evaluated in concretes with low cement content in order to thoroughly show that technical implications are known: the possible negative (or positive) implications of reducing cement content in concrete would be measured. For this task, some pioneer works from recognized researchers of concrete could be used as starting models (Popovics, 1990; Mehta, 2009; Wassermann; Katz; Bentur, 2009) since they all show that the lower the cement content, the more the durability, and even the strength, for fixed w/c ratios. All research on the theme could take into account concrete design technology, including the advantages and the behavior of concrete improved through the use of dispersants and aggregates packing technology, among others.

These actions could be the first step towards convincing the market in relation to cement reduction feasibility, which is one of the most difficult actions embedded in the development and implementation of this strategy. Market participation in this strategy will depend on a massive and solid source of data that proves the feasibility of this approach. The market does not have reason to believe in the idea without concise proof; without proof there would be no reason to risk its current practices, methods and knowledge. Changes in well-established business practices are always a risk that some do not want to take, however they can accept a new idea when there is proof that something can be done in a better way. Another important task is related to the commercial aspects as we are involving not only the concrete producers, but also the cement manufacturers. They would also need to have other alternatives that avoid decreasing their profits; on the contrary, they would not support the development of the concept. So, in the near future the cement industry perhaps will not sell only pure or blended cement (raw materials), but also final products, such as concrete. This is a market opportunity that could really decrease the cement industry’s opposition to a reduction in cement consumption.

International concrete standards, for reasons discussed in topic 3.1, can also need revision to allow the introduction of a new low strength concrete design methodology, including economizing cement. But this action depends on previous proof that this is technically feasible and also a huge management effort by international scientific research institutes.

Besides developing technical methods and convincing the market about the new strategy – which are medium or long term goals –, other, really long term goals, are also needed. The main one is to make the reduction of cement consumption at local construction sites possible, where ready-mix concrete is not available. Site-made concrete is certainly the most eco-inefficient due to the fact that it does not always employ effective design control by skilled professionals. So this type of construction practice needs to gradually disappear and be substituted by industrialized cement based materials, strategy that could be developed by cement industry which could sell not only pure cement but also dry concrete mixtures.

5. Conclusion

Nowadays, the continually increasing production of cement is tending to push CO₂ emissions upwards to levels incompatible with global warming. Contributing to change this scenario, cement producers are taking actions that are focused on improving cement production with the objective of decreasing
emissions, but these alone are not enough. New strategies focused on cement use optimization are needed, and have technical support since some of the works from important concrete researches have shown that it could have positive impacts on strength and even durability.

This paper explores a new model for quantifying the potential of optimizing binder content in concrete, and the relation between this strategy and clinker replacement by mineral admixtures. The two eco-efficiency indexes created – binder intensity (BI) and CO₂ intensity (CI) – allow measuring, in a quantitative way, how and to what degree it is possible to decrease concrete impacts on the environment.

A concise benchmark from literature data was created and analyzed. The use of the two indexes together proved to be a good way of assessing concrete eco-efficiency and, as a consequence, to allow the production of more eco-efficient concretes. Decreasing BI values means producing concretes with less binder to get the same mechanical strength, which provides the decrease of CI. But a low CI do not necessarily indicate low BI due to the fact that the concrete could be mixed with a high clinker replacement but also a high binder content. So, isolated, only a low CI or a low BI is not enough to produce a really “green” concrete. In relation to this, the availability of fly ash and blast-furnace slag must be taken into consideration as they are not infinite.

The minimum BI analysis showed that high strength concretes have a tendency to be more eco-efficient than lower ones. For low strength concretes, BI is higher perhaps due to the limits imposed by international standards. The high BI found in these concretes allow concluding that the proposed strategy of optimizing cement content in concrete has considerable potential for decreasing CO₂ emissions. This is even more effective in low strength concretes because they represent the largest proportion of the world’s concrete production. Although only a small amount of data from ready-mix concrete producers was evaluated and the assessment was somewhat superficial, the same trends appeared.

From the observed trends, a long-term, although difficult course may be elaborated that lists the commercial and technical challenges facing the international scientific community which can lead the world to a higher environmental goal. These challenges are: 1) to develop a concise international market practice benchmark; 2) to measure the real potential of the action taken; 3) to develop new methods of designing concrete, including the correct use of new dispersants, aggregates, binder and packing technologies; 4) to guarantee the technical performance of new low cement concretes in terms of durability, fire resistance, compressive strength, impact strength, fatigue and fracture, among others; 5) to change international standards regulating minimum cement content in concrete; 6) to convince cement and concrete producers of the real feasibility of the strategy in technical and economical terms; and 7) to propose a long-term goal agenda, where a change in the basis of the industry is needed in order to develop a new family of ready-mix cement based materials, thereby avoiding the currently inferior practice of producing homemade mixtures. All this roadmap needs is to be managed by relevant international scientific research organizations, which are the only ones with the power to organize such a massive and widespread effort toward the sustainability tripod of the cement supply chain.
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Abstract

This paper sets out the preliminary findings of a government funded Knowledge Transfer Partnership (KTP) between the School of Architecture & Landscape, at Kingston University London, and Clive Chapman Architects in Twickenham, London. The main aim of the project was for the architectural practice to gain in-house expertise in sustainable and environmental design and to develop and establish a specialist sustainability unit. The paper will examine how we tackle climate change in the new build residential sector in England and the practicality of implementing various requirements of the current and proposed UK legislation, sustainability codes, and local authority planning requirements. The paper briefly outlines the KTP project and the very significant benefits of knowledge transfer between academia and industry. It will focus on the global, national, regional and local requirements for energy strategy including building regulation requirements, sustainability codes and local authority requirements. A case study is described which takes an individual dwelling, typical of new housing in the UK, and models the impact of different design strategies on achieving the various requirements. This includes a description of the models that are currently being used to carry out assessments and the relative advantages and disadvantages of each. The design strategies tested include the use of different levels of fabric insulation and airtightness, ventilation strategies, fuel types, and renewable energy systems. These are then assessed against national, regional and local requirements and the impact on energy consumption and carbon emissions are quantified and presented. Preliminary findings of work already completed have shown that achieving higher levels of the Code for Sustainable Homes is prohibitively expensive and the funding systems for financial support from the Government are inadequate. The findings also show that the methods being used for quantifying energy and carbon emissions are fraught with problems and there are many conflicts in the interpretation of the requirements at different levels. As a result, there needs to be a more consistent set of guidelines at national, regional and local level, and a need for clearer definitions.

Keywords: climate change, building sector, energy, carbon emission requirements, implementation
1. Knowledge Transfer Partnerships (KTP)

1.1 Knowledge Transfer Partnerships (KTP)

Knowledge Transfer Partnerships are Europe’s leading programme for helping businesses to improve their competitiveness, productivity and performance. KTP achieve this by helping organisations to access knowledge, technology or skills from the UK’s knowledge base, which includes universities, further education colleges and research and technology organisations.

The knowledge sought is embedded into the organisation from the knowledge base through a project undertaken by a recently qualified graduate recruited to specifically work on that project (known as the Associate).

The Government encourages the formation of Partnerships by making a grant to the Knowledge Base Partner as a contribution to the costs of the KTP Project. The Company Partner also pays a share of these costs. This results in there being less risk for companies that want to invest in development through partnering with a knowledge base.

1.2 Aims of this Knowledge Transfer Partnership (KTP)

The demand for environmentally sustainable building design is presently driven by legislation and clients. In order to respond to this increasing demand and to remain competitive Clive Chapman Architects (CCA) collaborated with the School of Architecture & Landscape at Kingston University London (KUL).

This KTP will integrate sustainability into the architectural process and create a new business model that will introduce a new capability and expertise into the company.

2. The residential new building sector in England

There is now very strong evidence (IPCC, 2007) that since the late 1800s the earth’s average surface temperature has risen by 0.74°C. Since this period, there has been an ever increasing consumption of fossil fuels as oil, gas and coal, significant deforestation, and the practice of farming methods that result in emissions of six principal greenhouse gases (UN, 1998): Carbon Dioxide (CO₂), Methane (CH₄), Nitrous Oxides (N₂O), Hydrofluorocarbon (HFC), Perfluorocarbon (PFC) and Sulphur Hexafluoride (SF₆).

The first reason for the current concern about climate change is the rise in atmospheric carbon CO₂ concentrations indicated in parts per million as shown in Figure 1.
The second reason concerns the speed of the recent warming. Average global temperatures have risen by 0.55°C since 1940. During the ice age and warm interglacial periods the mean temperature changed between 4°C and 7°C, however the process took about 5,000 years (IPCC, 2007).

In 2006 the UK was responsible for a total of 652Mt of CO₂ equivalent of greenhouse gas emissions (including Land Use, Land Use Change and Forestry) (DEFRA, 2008a). The UK Governments Department of Business, Enterprise and Regulative Reform has quantified the CO₂ contribution as accounting for 85% of these emissions (BERR, 2008).

Data shows (DEFRA, 2008b) that the building sector accounts for 63% of this, and the residential sector is responsible for about 27% of the total CO₂ emissions in the year 2006.

The sources of the CO₂ emissions in residences in 2005 have been published (DCLG, 2007). The heating sector (water and space) is responsible for 73% of the residential CO₂ emissions.

In 2006, London produced a total of 50Mt CO₂ from the consumption of energy in the domestic, commercial, industrial and ground transport sectors. This amount of CO₂ emissions represents 10% of the total CO₂ emissions of the UK (excluding emissions arising from aviation) (DEFRA, 2008c).

In order to prevent catastrophic climate change and be on course for the Government’s national targets, the Mayor’s target for London is to stabilise CO₂ emissions in 2025 at 60% below 1990 levels, as shown in Figure 2. London therefore must save 33 million tonnes CO₂ emissions or 4% per year.
3. International, national, regional and local energy strategy requirements

3.1 The international, national, regional, local levels

Different levels of hierarchy including international, national, regional and local intergovernmental/governmental institutions define energy strategies and set out targets for tackling climate change.

The UNFCCC is the overall framework for intergovernmental efforts to tackle the challenge posed by climate change. One of the earliest obligations of the UNFCCC parties is the Kyoto Protocol that came into force in 2005.

The core commitment under the protocol requires each committed industrialized country to ensure that its total emissions from the main six greenhouse gas sources (CO₂, MH₄, N₂O, HFC, PFC, SF₆) do not exceed agreed levels of emissions. The UK agreed in the Kyoto Protocol to cut its greenhouse gas emissions by 8% by 2012.

In order to implement the EU targets and greatly affect awareness of energy use in buildings and to lead to substantial increases in investment in energy efficiency measures within these buildings, the Energy Performance of Buildings Directive (EPBD, 2002) came into force in 2003.

The EPBD aims to ensure that new buildings meet the set requirements, make Energy Certificates available when buildings are constructed, sold and rented and to inform the users of buildings about methods and practices to enhance energy performance.

The Directive required all countries of the EU to transpose these EU targets into national law by January 2006.

In response to this directive, the UK Government set targets to cut the national CO₂ emissions by 80% by 2050. By 2020, 20% of the European Energy Consumption will be saved through improved energy
efficiency and the renewable energy supplies will be increased by 10% by 2010, with an aspiration for this level to double by 2020.

To achieve these targets, the Government amended the Building Regulations (BR) Approved Document Part L in 2006 (ODPM, 2006) and currently is consulting on the changes that will come into force in October 2010. Compliance with BR is mandatory.

In addition to these changes the UK Government introduced the Code for Sustainable Homes (CSH) (DCLG, 2008) in 2007. The CSH is an environmental assessment method for rating and certifying the performance of new dwellings. The CSH rates dwellings for their environmental credentials from level 1 (enhanced sustainability) to level 6 (zero carbon).

Since May 2008 it has been mandatory for all new homes to have a CSH rating included in the Home Information Pack (HIP) as information to prospective purchasers of properties in England. For private dwellings it is currently possible to have a nil rated CSH certificate where an assessment has not taken place. All affordable housing has to currently comply with CSH Level 3 and is expected to comply with Level 4 from 2010.

On a regional level the Greater London Authority (GLA, 2004a) published it’s Energy Strategy in 2004. The strategy aims to improve London’s environment, reduce the capital’s contribution to climate change, tackle fuel poverty and promote economic development by using less energy (being lean), using renewable energy (being green) and supplying energy efficiently (being clean).

The objectives arising from this strategy are 20% reduction in CO₂ emissions (relative to 1990 levels) by 2010. In the longer term, emissions will be reduced by 60% (below 2000 levels) by 2050. In addition, all major developments are expected to generate 10% of their energy needs from on-site renewable energy (where feasible). This target will be extended to 20% by 2020. The London Renewables Toolkit (STI, 2004) provides guidelines for planners, developers and consultants in order to integrate renewable energies into new developments.

Richmond upon Thames published it’s Core Local Development Strategy (LBRUT, 2009a) in 2009. The Core Strategy sets out the Strategic Planning Framework of the borough over the next 15 years.

The vision of Richmond upon Thames is to see a borough that is inclusive, that puts the environment at the core of its services, delivers high quality public services that reflect the needs of all its people, and addresses its challenges by harnessing the capacity of all its partners on the public, private, voluntary and community sector.

The Borough requires every new development to comply with its supplementary planning document, the Sustainable Construction Checklist (LBRUT, 2009b). The Checklist requires an excellent environmental rating for all new residences which is equivalent to a Code for Sustainable Homes rating of Level 3. The predicted site CO₂ emissions have to be reduced by at least 20% through the use of on site renewable energy. In addition, every planning application has to incorporate a sustainability statement.
3.2 Renewable energy technologies

All levels of hierarchy, from international to local, seek to implement the objective to cut greenhouse gas and/or carbon dioxide emissions. To implement these objectives the specific targets are to improve energy efficiency, to improve the energy performance of buildings and to incorporate renewable energy technologies; targets that are all interlinked with one another.

But on different levels of hierarchy the three targets are not approached holistically.

In addition, various terminologies and definitions are used for renewable energy technologies, including renewable energies, micro-generation, macro-generation to energy-generating technologies and the required percentages range from ‘where feasible’ to a compulsory 10% or 20%.

4. Typical new housing case study

4.1 The exemplary dwelling

The dwelling chosen for this research is a real development located in a suburban area in the South West of London. The dwelling is a detached property, comprising two storeys, with a total floor area of approximately 160m².

Figure 3: Site Plan and ground floor of exemplary dwelling, Architect James Deasley

4.2 The calculation model

All calculations have been performed with the National Home Energy Rating (NHER) Plan Assessor Version 4.2.28.
The NHER Plan Assessor software is government approved and authorised for Standard Assessment Procedure (SAP), Environmental Impact (EI), Target Emission Rate (TER), Dwelling Emission Rate (DER) calculations and for issuing Energy Performance Certificates (EPC).

In addition to the above the software predicts the annual energy consumption of dwellings based on BREDEM-12 (Building Research Establishment Domestic Energy Model) which is more comprehensive than the Standard Assessment Procedure.

### 4.3 The assumptions

It is assumed that the dwelling is naturally cooled, no secondary heating system is specified, no chimneys and open flues are present and in total three extract fans are installed in kitchen and bathrooms.

The heating systems tested include gas boiler, warm air (efficiency 100%), warm air with heat recovery (80%), biomass boiler, ground source and air source heat pumps and a communal CHP system. They are time and temperature zone controlled.

Appropriate systems to comply with the local planning requirement to offset at least 20% of the predicted CO₂ emissions by renewable energies have been tested.

The case studies therefore include renewable energy systems that are reasonable in a suburban context, such as photovoltaic elements, solar hot water elements, biomass boiler, ground source (efficiency 320%) and air source (efficiency 250%) heat pumps.

The two different types of construction tested for this case study are as follows:

1. The dwelling complies with Part L1A of the Building Regulations.

2. The dwelling exceeds the requirements of Part L1A. The Government will require all new housing to comply with CSH Level 4 by 2010 (for affordable housing) and 2013 (for private housing) and therefore the second range of case studies will achieve compliance with CSH Level 4.

<table>
<thead>
<tr>
<th>Building Element/Building System</th>
<th>Type 1 – standard construction</th>
<th>Type 2 – improved construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor, external walls, roofs</td>
<td>0.25W/m²K</td>
<td>0.12W/m²K</td>
</tr>
<tr>
<td>Windows</td>
<td>2.0W/m²K</td>
<td>0.8W/m²K</td>
</tr>
<tr>
<td>Doors</td>
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</tr>
<tr>
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<tr>
<td>Transmission heat loss coefficient y</td>
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<td>0.08W/m²K</td>
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</table>
4.4 Results of the analysis

4.4.1 Carbon Dioxide emission calculation methodologies

Different calculations are required to demonstrate compliance solely with the energy performance of new build dwellings. To prove compliance with BR AD Part L1A and to produce Energy Performance Certificates (EPC) for SAP-ratings, SAP 2005 calculations are required.

For both verifications SAP determines the CO₂ emissions arising from the predicted energy demand including main and secondary heating, cooling, ventilation, fans and pumps and lighting. The CO₂ emissions arising from cooking and appliances are not accounted for.

The assumptions that are made for the secondary heating and the energy efficient lighting are different in the calculations for Part L1A and for the determination of the SAP-rating.

For Part L1A the calculations determine the CO₂ emissions of the actual dwelling (DER) and these are compared with those of a notional dwelling, defined as the Target Emission Rate (TER). To comply with BR, the DER has to be equal to, or lower than the TER.

For Part L1A it is assumed that a secondary heating appliance always meets part of the space heating demand. The fraction provided by the secondary heating system is in accordance with the definitions in SAP (BRE, 2008) as shown in Table 2.

Table 2: Fraction of heat supplied by secondary heating systems

<table>
<thead>
<tr>
<th>Main heating system</th>
<th>Secondary system</th>
<th>Fraction from secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>All gas, oil and solid fuel systems</td>
<td>all secondary systems</td>
<td>0.10</td>
</tr>
<tr>
<td>Micro-cogeneration</td>
<td>all secondary systems</td>
<td>see Appendix N</td>
</tr>
<tr>
<td>Heat pump</td>
<td>all secondary systems</td>
<td>0.10</td>
</tr>
<tr>
<td>Electric storage heaters (not integrated)</td>
<td>all secondary systems</td>
<td>0.15, 0.10</td>
</tr>
<tr>
<td>- not fan-assisted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- fan-assisted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated storage/direct-acting electric systems</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Electric CPSU</td>
<td>See Appendix F</td>
<td></td>
</tr>
<tr>
<td>Electric room heaters</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Other electric systems</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Community heating</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes:
1. See also Appendix A.
2. If an off-peak tariff is present, an electric secondary heater uses the on-peak tariff.
Where a secondary heating system is fitted, the efficiency of the actual appliance is used. Where a chimney or flue is provided but no appliance is installed, then an efficiency of 20% is assumed where a gas point is located adjacent. If there is no gas point, an efficiency of 37% is assumed. Where no secondary heating system is fitted, electric room heaters are assumed with an efficiency of 100%.

For lighting, a fixed assumption of 30% low energy lighting is made by Part L1A, with a minimum of one energy efficient light fitting per 25m² floor area, or one for every four fixed lighting fittings.

To determine the SAP-rating for EPCs, the Environmental Impact Rating (EI) and the Energy Efficiency Rating (EE) need to be calculated. The calculation procedures for both ratings are also based on the total CO₂ emissions (DER) and the total energy costs based on SAP respectively.

However, contrary to Part L1A, for EPCs secondary heating systems are calculated as designed for the dwelling. The efficiencies of the systems are as specified by the manufacturer. Where a secondary heating system is specified, the fraction from secondary heating is as indicated in Table 2 above. Where no secondary heating system is incorporated in the actual dwelling, the fraction of the secondary heating system is zero.

For EPCs the CO₂ emissions from lighting are based on an average energy consumption for lighting in UK houses of 9.3kWh/m² if no low-energy lighting is used. The fixed lighting systems are taken into account by including a correction factor.

Therefore, the CO₂ emission results of Part L1A and EPC calculation procedures vary as indicated in Figure 4 but are expressed using the same terminology “DER”.

In addition, Figure 4 shows the CO₂ emissions based on the assumptions made by NHER. In comparison with the SAP 2005 calculation procedure for Part L1A and EPCs, NHER includes the emissions arising through cooking and electrical appliances in the dwelling.

Figure 4: Calculated CO₂ emissions for house type 1 for EPC, Part L1A and NHER
4.4.2 Carbon emissions

Figures 5 and 6 demonstrate that the best heating option in terms of CO$_2$ emissions is not the best option in terms of energy demand.

Figure 5: CO$_2$ emissions for different heating strategies for house types 1 and 2

Figure 6: Energy demand for different heating strategies for house types 1 and 2

The biomass boiler has for both construction types the lowest DER but the highest energy demand. Whereas, the options with ground source heat pumps (GSHP) as heating systems show the best performances in terms of energy demand but have average DERs.
These differences are as a result of the factors SAP uses to convert the energy of the fuel into CO₂ emissions. Wood pellets for biomass boiler emit 0.025kgCO₂/kWh and electricity, the fuel for GSHPs, emits 0.422kgCO₂/kWh.

Therefore the definition of the DER as a decisive factor to conserve fuel and power is in conflict with the target to implement energy efficient heating solutions. Furthermore it is likely, that in the near future the proportion of electricity generated by renewable energy systems will increase and therefore the current heating systems running on electricity will have lower CO₂ emissions in the future.

4.4.3 Cogeneration

One target of the Mayor of London (GLA, 2004b) is to improve the use of efficient technologies, such as Combined Heat and Power (CHP) systems. Gas CHP systems are defined as Low or Zero Carbon Technologies in the CSH (DCLG, 2009) but are not recognised as renewable energy systems as defined in the London Toolkit (STI, 2004).

Therefore, gas CHP systems can award credits in the Energy 7 “Low or Zero Carbon Technologies” criterion in the CSH, but gas CHPs do not count towards the 20% renewable energy requirements of some Boroughs.

According to Grinfeld (BSD, 2009) CHP systems achieve 30% higher efficiencies than systems that produce heat and electricity separately.

In addition, Figure 7 shows that the CO₂ emissions of a communal gas CHP systems calculated according to the Part L1A and NHER are the lowest of the systems tested.
Gas CHP systems are therefore significant energy saving measures, although in practice they are not often incorporated, as the capital costs for CHP systems are higher than those of gas boilers and in order to receive planning permission, additional investments have to be made for the incorporation of renewable energy systems.

### 4.4.4 Electricity consuming systems

Figures 5 and 6 show, among other things, the energy and CO₂ performances of warm air heating systems with and without heat recovery (HR).

The warm air heating systems have the highest CO₂ emissions of the systems tested. However the energy demands of both systems are less than those of the biomass boiler and of the gas boiler, because of the 100% efficiencies of the electricity consuming systems. Again it is not reflected in the CO₂ conversion factors applied by SAP that more electricity will be generated by renewable technologies in the future.

In addition, figures 5 and 6 show that the HR system reduces the CO₂ emissions and the energy demand in the case of the improved construction, whereas the HR slightly increases both in the standard construction as the system is running on electricity. Therefore the more airtight the building construction, and the higher the thermal resistance of the building materials, the higher the savings achieved through the HR.

The principle of the HR system is to preheat supply air, using the heat from the extracted air. Therefore HR systems act in the same way as air source heat pumps. Nevertheless HR is not recognised as renewable energy technology, whereas ASHPs are on international level.

### 4.4.5 Renewable energy technology/LZC calculation methodologies

On a national and regional level a rating against the CSH Assessment is required, although where an assessment has not taken place, a nil-rated certificate is allowed.

The CSH Energy 7 criterion awards credits for the incorporation of Low or Zero Carbon Technologies (LZC). To demonstrate compliance with Energy 7, the CO₂ emissions of the actual dwelling are compared with those of a “Standard Case”, as defined in the CSH Technical Guide (DCLG, 2009). The Energy 7 spreadsheet tool helps facilitating the required calculations.

However, on a local policy level a similar requirement, to offset the predicted CO₂ emissions by at least 20% on-site renewable energy systems, becomes a mandatory criterion.

The systems that are accepted as renewable energy vary on different levels and a generic definition is hard to find. In order to demonstrate compliance, complex and confusing calculations are required:
To establish the total CO₂ emissions of the dwelling, the CO₂ emissions must first be calculated with SAP 2005. The procedure then requires the Energy 7 CSH calculation tool to establish the additional CO₂ emissions through cooking and appliances, which are not reflected in the SAP 2005 calculation procedure. These total predicted CO₂ emissions form basis for the determination of the required 20% offset through renewable energy systems.

To determine the CO₂ savings achieved through the incorporated electricity generating renewable energy systems, the CO₂ emissions of the actual dwelling are compared with a base case with the same dwelling design and the same heating system, but without the electricity generating systems. This calculation becomes even more complex if the renewable energy systems incorporated provide heat instead of electricity.

Furthermore, as can be seen in Figure 8, the amount of energy generated from additional renewable energy technologies increases with improved construction in the case where the heating system is the renewable technology, e.g. GSHP, ASHP, biomass boiler. That is, if the basic design of the building is better, then the amount of renewable energy technologies that has to be incorporated into the development to achieve the 20% requirement is greater. This clearly, does not promote good basic design.

![Image of Figure 8](image)

Figure 8: Amount of energy produced by the renewable energy technologies incorporated to house types 1 and 2 to meet the 20% renewables requirement

### 4.4.6 Costs

The costs for the additional sustainability requirements arise through improved building construction, improved building services, the costs for the renewable energy technologies and the procedure for the CSH assessment and certifications.

From experiences it can be seen that the additional costs of achieving CSH Level 4 and to incorporate 20% renewable energy systems to a typical dwelling range between £10K and 15K.
Figure 9 shows the predicted CO₂ emissions and payback periods for various renewable systems. It is assumed that the costs for the full installation of PV elements are £5,800, of solar hot water elements are £795, of a biomass boiler are £5,000, of an ASHP are £5,000 and of a GSHP are £12,000.

It can be seen that the biomass boiler has the shortest payback period time of 5 years and the GSHPs and ASHPs have the longest payback periods of 24 years. The installation of a GSHP is complex and therefore cost intensive. Although the ASHP has low capital costs itself, the contribution of the heating system towards renewable energies as defined by the Borough, is very low. This is because firstly, the efficiency of the system is fixed at 250% by SAP 2005 even though the CoP of the systems are better according to manufacturers, and secondly the ASHP running on electricity is compared to a base case with a gas boiler to constitute the % renewable energies. Therefore additional renewable energy systems have to be included which generate additional costs.

The best system in terms of CO₂ emissions is the communal CHP. With the gas boiler the CHP has the second shortest payback period of 11 years. But the additional costs of the CHP system itself have not been included, as the gas CHP is not recognised as a renewable energy system.

Figure 9: Predicted CO₂ emissions (NHER), the contribution towards % renewable requirement of the Borough and the payback periods of different renewable energy systems of house type 2

To overcome the financial barriers several schemes have been put into place by the UK Government. Until 2011 grants are available under the Low Carbon Building Programme for Low or Zero Carbon
Technologies for new build residential developments. Under the Renewable Obligation certificates can be sold to energy suppliers for each MWh generated. Stamp Duty Exemptions up to 4% are available for the first acquisition of zero-carbon homes.

From April 2010, a Feed-in-Tariff will be paid for every kWh of electricity generated by renewable energy systems and a Renewable Heat Incentive is announced to be launched by 2011.

However, the financial incentives are complex and refer to terminologies such as renewable energy systems, energy-generating technologies, energy-saving technologies, micro-generation, macro-generation and low or zero carbon technologies, which is confusing, and they cover only a fraction of the costs of a sustainable new building.

5. Conclusions

To implement the energy and CO₂ requirements in the new residential sector in England, three strategies are pursued: to go easy on resources (be lean), to improve energy efficiencies of systems (be clean) and to use non-fossil fuels (be green).

The implementation of these three strategies is regulated by the mandatory BR Part L1A and the optional CSH on national policy level and the mandatory supplementary sustainability planning documents on regional and local level.

The study undertaken shows firstly, that these regulations are not in line with each other and vary from Region to Region and from Borough to Borough. Their implementation therefore becomes confusing and unnecessarily complex.

Secondly, the applied methodology of implementing the strategies “be lean” and “be clean” are confusing and conflicting.

In order to demonstrate compliance with BR and to produce EPCs, SAP calculations are required.

The case studies show, that the SAP calculation used to predict the CO₂ emissions of a dwelling disregard the energy demand of cooking and electrical appliances. The predicted emissions that are used as evidences for BR compliance and that form the basis for SAP-ratings are therefore unrealistic.

Furthermore, both calculation procedures (BR, EPCs) use the same terminology “Dwelling Emission Rate”. But the calculations are based on different assumptions that result in two different emission rates which is confusing and a potential source for errors and confusion.

In addition, the SAP tool does not reflect in its calculation that the heating systems that run on electricity and therefore are more energy efficient than conventional gas boilers, such as GSHP, ASHP and warm air systems, will be less carbon intensive in the future, as a higher proportion of electricity will be generated by non-fossil fuels. The currently high carbon conversion factors for
electricity result in high dwelling emission rates. Although more energy efficient, it is likely that these systems are not considered as heating systems. But these new dwellings will be the building stock of the future.

Thirdly, the study indicates that the methods applied to implement the strategies “be clean” and “be green” are conflicting and their definitions confusing.

A clear definition of “renewable energy technologies” is hard to find and different terminologies, such as “low or zero carbon technologies”, “micro-generation”, “macro-generation”, “energy saving technologies” and “energy generating technologies” are used.

For example air source heat pumps are not listed as renewables in regional guidelines, but are considered as renewables on national level, and, heat recovery systems, that use the same principles as ASHP are not recognised as renewable systems at all.

In order to determine the mandatory planning requirement of some Boroughs, that is to incorporate 20% renewable energy technologies on site, the calculation procedure is confusing. Firstly a clear definition is required, and as the study shows, the calculation methodology advantages lower quality construction standards. Secondly, the calculation conflicts with the CSH Energy 7 “Low or Zero Carbon Technologies”, which addresses a similar, but by definition, different requirement, by partly using the Ene 7 calculation tool and partly following its own calculations.

Furthermore, the case studies show that the cogeneration of heat and electricity with a gas CHP system is more energy efficient than their separate production. However, gas CHP systems are not considered as renewable energy systems and therefore do not count towards the requirement to incorporate 20% renewable energy technologies on-site. Therefore, costs for the CHP and the additional 20% renewables are often the criterion to reject this more energy efficient system.

In conclusion, the implementation of the energy and carbon requirements in England is unnecessarily confusing, complex and therefore time-consuming and generating costs. To overcome these barriers and to make the implementation of the national energy and CO₂ requirements successful, a number of recommendations can be made:

1. Regulations are required that are valid on every policy level in England and the UK respectively.

2. The calculation procedures for compliance with BR and to provide EPCs need to be adjusted. In order to give a more realistic prediction of total CO₂ emissions these calculations require including the energy demand for cooking and electrical appliances.

3. The required evidences should be based on the predicted energy demand of the dwelling expressed in kWh/m²yr, rather than on the CO₂ emissions in kg/m²yr. This will allow overcoming the conflicts between the energy efficiency of systems and the fuel type of the systems.
4. One terminology and a clear definition of “renewable energy technologies” needs to be agreed upon, that is valid in England and the UK respectively. Simple and clearly defined calculation procedures are required to demonstrate compliance with these renewable energy requirements.

5. The financial incentives need to be made more transparent and easily accessible in order to overcome the financial barriers.

References


DEFRA (2008c) *Local Authority Carbon Dioxide Estimates 2006, Statistical Summary.*


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All amounts in EURO

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