EDITORIAL

A conference for Masters students in sustainable buildings
Luisa Brotas, Fergus Nicol, Malcolm Cook and Darren Woolf

The amount of energy used by a building can vary enormously depending on its relation not just to the climate and the design and operation of the building, but also to the habits and behaviour of its occupants. The core and specialized engineering science and architectural disciplines are important elements in the support of building design but not enough on their own. People and buildings are parts of a system, which needs to be safe, comfortable, sustainable, resilient and affordable for its inhabitants. A successful building is one, which provides the means for those who live in it to achieve these aims, and does it with the minimum use of resources. A good building design involves addressing CO$_2$ emissions at all stages of the life cycle and mitigating the impacts of climate change on the built environment and its human inhabitants.

There are a growing number of Masters courses designed to enable students, and in many cases practitioners, to gain the knowledge needed to design good low-carbon buildings that are comfortable to the occupants and have good air quality. In particular students commit a great deal of energy and ingenuity in writing their Masters’ dissertations but rarely get an opportunity to present their work outside the confines of their own University. As a result a lot of interesting work can become locked away – at best in the school archive, at worst only in the memories of the writer, supervisor or examiner.

The process of writing a paper of just a few pages from the wealth of data accumulated in writing a masters dissertation can be challenging and instructive. This conference begins to address this situation by providing a forum to discuss short papers by Masters students who are near the end of their course or who have completed in the last two years. The subject of their paper usually reflects that of their dissertations, but may result from other work they have done if this results in an interesting and informative paper.

The conference also provides a forum for students of architecture, engineering or related disciplines from different universities to meet one another and exchange information and discuss important topics. The conference also provides an environment for students to contact potential employers. All papers and presentations are uploaded to the NCEUB website where they can be accessed and form a reference source for other students to get ideas and information.

See the website http://www.nceub.org.uk for further details and other activities of NCEUB.

Active learning and peer evaluation are strongly encouraged and students are invited to vote for best presentations awards. Participants have rated these experiences very positively.

People and Buildings conference MC2014

The 2014 conference was held on 19th September 2014 at the London Metropolitan University, School of Architecture Sir John Cass Faculty of Art, Architecture and Design, Central House, 59-63 Whitechapel High Street, London E1 7PF. The conference was attended by 47 eligible students and 8 members of teaching staff from departments of architecture or engineering in 10 UK and 5 overseas universities.

Twenty-two papers were presented by the students in four sessions. Papers made available in this volume of proceedings address a wide variety of subjects and research approaches from energy efficiency, the reliability of existing energy models, daylighting, building and systems simulation, test chamber experiments, building and user surveys and occupant comfort. A few memorable papers are introduced below to illustrate the breadth of the subject matter introduced.

In her paper Air Flow and Thermal Comfort in an Educational Building, Emilia Targońska from Loughborough University presents the results of her detailed monitoring of the thermal conditions in a lecture theatre and its use to predict the comfort of the occupants. Results of the questionnaire survey were compared to those predicted by the PMV index. Energy consumption obtained by simulation was compared to a typical benchmark. Proposed solutions to improve comfort levels based on findings from the survey and literature review were further assessed.

Bingyun Liu from UCL in her Empirical study: investigating the effect of CO$_2$ concentration on reported thermal comfort investigated the impact of varying CO$_2$ concentrations to the thermal sensation of comfort, in a study undertaken in a climatic chamber. A proposal is put forward to a modified PMV model including the effect of CO$_2$ variable.
A detailed questionnaire study of a small hotel in Oxford forms the basis of Analyzing the factors that contribute in making a hotel in UK sustainable and energy efficient by Gaurav Shahane of Oxford Brookes University. The paper looks not only at the actual energy efficiency of the individual hotel but uses questionnaire surveys to assess the attitude of hotel management and guests to the importance of sustainability and energy efficiency in their running of this particular hotel and, in the case of guests, in their choice of hotel.

Parvaneh Khodadadi Andebil of Brunel University writes about Computational Fluid Dynamic (CFD) Modelling of a Novel Active Phase Change Material (PCM) Cooling System describing an experimental evaluation of the use of a PCM in an office room. Results are transposed to CFD software simulating the potential of the cooling system and reduction of Energy use and CO₂ emissions for maintaining comfort.

Carlos Val of London Met University, in his paper Daylighting and LENI Calculations introduces the Lighting Electric Number Indicator - a measure of the electric energy in kWh/m²/year consumed in lighting a building. LENI was firstly found in the EN:15193 2007. This norm gives two calculation methods: a quick method, based in defaults; and a comprehensive calculation of the different factors, which yields much lower estimations. Carlos introduces the ideas behind the method and how it can be used in energy performance analysis in particular its recent inclusion in Building Regulation Part L. This addresses the contribution of daylight to the energy saving from lighting. Results obtained from different methods are compared with advanced daylight simulations.

George Papachristou of Loughborough University addresses The feasibility of natural ventilation in plus energy houses in Germany. This research is timely given the emphasis in recent standards in promoting mechanical ventilation with heat recovery as a solution to reduce CO₂ emissions in buildings. A comparison of different CO₂ controls demands for ventilation strategies highlight the potential energy savings while maintaining acceptable indoor air quality and thermal comfort.

Richard Bowman from Oxford Brookes University in his paper In Support of Willingness to Change Energy Consumption Habits discusses theories of occupant behaviour and social influence on one side and awareness of energy savings and energy cost/efficiency on the other, as mechanisms to affect energy use in buildings and its impact on the environment. His study is based on a questionnaire survey to occupants about their behaviour and willingness to act in preservation of the environment.

The award for best presentation, which was voted by the audience, was presented to three people. Therefore a joint best presentation was attributed to Christopher Cáceres-Araya from UCL with the paper Should schools located in polluted areas be naturally ventilated? : A case study from Chile, to Francesco Babich from Loughborough University for the work Are ventilation cooling towers an important element of plus-energy houses in southern Europe? and Simon Phillips from Loughborough University with the paper How does a well-insulated building, during a UK heat wave, perform in comparison to its predicted performance?

Darren Woolf of Hoare Lea Sustainability in London gave a presentation marking the 150th anniversary of the founding of Hoare Lea, a firm with a long association with sustainability and research in the built environment. His colleague, Doug Baldock, gave a presentation on how he completed his Masters dissertation on Down-scaling urban energy system modelling to large buildings whilst still working at Hoare Lea. Hoare Lea helped to fund the People and Buildings conference together with the CASS Faculty of Art and Architecture at London Metropolitan University. The conference was organised by Luisa Brotas and Fergus Nicol of the Network for Comfort and Energy Use in Buildings (NCEUB) with the assistance of Malcolm Cook of Loughborough University and Darren Woolf of Hoare Lea. Photos of the event are uploaded to NCEUB.

The Masters conference was considered a great success amongst participants. We hope it provides a useful source of reference for future research and work to be undertaken. As educators we promote the practice of dissemination of our research and hope to continue this event in the future.

Dr Luisa Brotas
London Metropolitan University
E-mail: l.brotas@londonmet.ac.uk

Prof Fergus Nicol
London Metropolitan University
E-mail: f.nicol@londonmet.ac.uk

Prof Malcolm Cook
Loughborough University
Email: malcolm.cook@lboro.ac.uk

Prof Darren Woolf
HOARE LEA
Email: darrenwoolf@hoarelea.com
ORGANIZING TEAM

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19th September 2014, CASS, London, UK

WELCOME and TIMETABLE
Dear Participant,

Welcome to the MC2014 People and Buildings conference. We of the organising group are always happy to be associated with this lively and interesting conference. The range of subjects covered is as wide as ever despite a small reduction in the numbers attending.

The conference is for masters level students on low energy and sustainable building courses in schools of architecture and engineering. The conference is a means to give masters students an opportunity to present their work to their peers beyond the confines of their own University.

Participants come from 8 UK Universities (Loughborough, Brunel, Oxford Brookes, London Met, UCL, CAT, Westminster and Sheffield) joined by students and staff from Canada, Czech Republic, Portugal, Uganda and India.

The 2014 conference is the fourth and will be held in Central House, the home of the Sir John Cass Faculty of Art, Architecture and Design from London Metropolitan University. Previous conferences have been hosted by the Westminster and London Metropolitan Universities and by Arup.

This year’s conference has been generously sponsored by Hoare Lea Engineering. We are happy to welcome Prof Darren Woolf Head of Building Physics at Hoare Lea who will give a short address about their research and about carrying out a masters’ project in industry. A special thanks is due to Prof Malcolm Cook from Loughborough University for facilitating this.

We are arranging for the collected papers from this conference to be published as an e-book complete with ISBN. We will announce to participants when the publication is ready and freely available to download at the NCEUB website.

Dr Luisa Brotas and Prof Fergus Nicol

Organising Committee MC2014, 4th People and Buildings masters conference


Network for Comfort and Energy Use in Buildings (NCEUB), Low Energy Architecture Research Unit
Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University,
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## 4th Masters Conference
### People and Buildings

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Container Architecture: a new emergent sustainable culture?

Marta Díez Amate and Luisa Brotas

MSc Architecture, Energy and Sustainability, Low Energy Architecture Research Unit, Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University, 40-44 Holloway Road, London N7 8JL

Abstract

This paper aims to extend the container architectural knowledge further while assessing if this relatively new type of architecture can be considered as a sustainable construction method. The research offers an overview about the main advantages and disadvantages about this kind of architecture showing examples while analysing them within a sustainable development concerning the social, economic and environmental dimension.

The thermal performance of the 40 ft container is assessed in terms of the energy consumption for heating and cooling (if an active system is in place) taking into consideration several parameters such as location, orientation and number of windows. The energy consumption of this type of architecture is also compared with the traditional one adopting construction methods such as concrete and wooden fabrics. Additionally, results are compared with the typical UK Benchmarks for dwellings in order to show if containers can comply with the minimum energy consumption recommended by the UK regulations as well as the amount of CO2 emissions emitted by the containers.

Keywords: sustainable development, container architecture, thermal performance, affordable, building elements

1 Introduction

Container architecture is a relatively new concept that was born in the nineties. Several architects, engineers and professionals involved in the construction sector have been motivated in reusing containers for architectural purposes. Companies such as Cargotecture in Seattle, Urban Space management in London, Habitaner in Spain, Green Container Residential Aid in Germany, Lot-ek in New York, Zigloo in Canada or De Maria in New Zeland have developed green architectural projects using containers as building units.

The growing problems of overpopulation, economic instability, environmental degradation and scarcity of energy resources are high in the agenda of researchers, scientists, academics, designers and consultants consciously involved in the built environment and their interaction with people. Within this panorama it seems necessary the reaffirmation of architecture as a regenerator element. “In the course of my life I became more and more convinced that the usual practice of architects to relieve the dominating disjointed pattern here and there by a beautiful building is most inadequate and that we must find, instead, a new set of values, based on such constituent factors as would generate an integrated expression of thought and feeling for our time. …such a unity might be attained to become the visible pattern for a true democracy….” – (Walter, 1956).

This paper assesses container architecture as a possible answer to our society needs. The analysis of its social, economic and environmental aspects in the frame of a sustainable development is presented hereafter.
2 The concept of sustainable development in container architecture

In the UN 2005 World Summit Outcome document, the concept sustainable development was redefined as a result of the heightened awareness of the strong connections between the extensive degradation of the environment coupled with socio-economic issues of poverty and inequality and concerns about future humankind health and existence.

The concept cradle to cradle extends sustainable considerations in the use of objects into a second life cycle. This further approach emphasizes in the importance of reusing objects and elements, providing them into a second life. (McDonough et al, 2002)

Due to the imbalanced trade in the container international markets and the cost of sending the containers empty to the original countries, around 56% of the containers used for the international transportation of goods are left empty in the ports as wasted materials. (The Geography of transport systems, 2009). Therefore, several architects, engineers and professionals involved in the construction sector have been motivated in reusing these containers as building elements. Can, therefore, container architecture be considered as sustainable architectural development?

2.1. Economical sustainable dimension

The most important advantages of using containers as building elements are their strength and durability, modularity, transportability and flexibility, availability and cost. Container architecture also offers an affordable way of manufacturing a building module to be repeated, reducing therefore drastically the construction cost and time. On the other hand, when ISO containers are modified, the ISO regulations cannot be applied anymore and new structural calculations should be developed incrementing the building cost. Consequently, the architect itself plays an important role in order to take as much advantage as possible of the containers strength while creating the design.

Ethan Anderson, Casey Pond and Jeffrey Scott founded DwellBox in Boone USA in 2008. They started a research about reusing shipping containers as an exercise to discover new building techniques. Their first idea was to employ the adaptive reuse of containers to create jobs and offer affordable housing solutions. The minimal amount of time required to build these dwellings proposed by the team plus the reduced price of a container ($1000 to $4000 depending of the container conditions) reduced drastically the cost per square foot in comparison to traditional construction methods such as concrete structures. In this sense, the architect Allam Kalkin has also proven that the cost of a modern home made from converted shipping containers can be as low as 73-90 dollars per square foot. (Lindem, 2011). In 2009 the company DwellBox received a $100,000 grant from the N.C. Green Business Found to continue their research in the use of containers as sustainable and cheap building elements. Dwellbox affirm that they have founded a way to save energy and an affordable architecture solution.

2.1. Social sustainable dimension

Container architecture has been seen as a solution for natural disasters as well as a solution for cheap housing in earlier times. Nowadays, new building typologies are emerging where container architecture is seen as a regenerator element for the urban fabric to redefine socio-cultural patterns within the current socio-economic crisis. For instance, the “Container City” or the “Riverside building” are container projects designed by the company Urban Space Management under the idea to regenerate one of the side areas of the river Thames in London. These two projects, an office building and housing building respectively, are to date,
a space which attracts a wide range of people to live and work there. Also, the architect Luis de Garrido in Spain designed a Zero Carbon house called “R4 House” including some sustainable strategies while using containers as building elements. He called this prototype “the answer” and defined them as a new architectonical and conceptual innovation capable to satisfy modern society needs. (De Garrido, 2009).

Jure Koknit, the author of the book “Container architecture”, also sees the use of containers as building elements as a solid decision to redefine social patterns. She writes “As a result, container architecture can offer new patterns in the relationship between people-building environments which are not always clear within the architecture made of conventional materials”. For instance, its flexibility and mobility between other advantages make this type of constructions adaptable to any situation. Koknit also affirms that “container architecture is presented here as a rational answer to a specific cultural and social problem breaking down aesthetic barriers”. (Koknit, 2009).

2.2. Environmental sustainable dimension
Following the Cradle to cradle principle, the conversion of retired shipping containers into building elements will extend their life cycle and hence reduce the impact of the embodied energy used to produce each container. It takes approximately 6481 kWh to produce 1 ton of steel from virgin products, 9000 kWh to melt down used containers, and around 400 kWh to convert used containers for building purposes. Almost 100,000 of the containers used for the transportation of goods, are left behind each year due to the cost in transporting them back empty to their origins. (SGblocks, 2014)

Vijayalaxmi cites: “If a new product is reused, then much more energy is saved because the destruction of an old product and manufacturing of a new product are avoided. This also implies a significant reduction in energy use and associated greenhouse gas emissions. (Vijayalaxmi, 2010).

Reusing containers as building elements consume less embodied energy than using traditional construction methods. In the article “Green from the ground up” published in The Tyee, green and sustainable buildings are studied by a group of experts as a result of months of research, interviews and investigation by the Carbon Shift hub. In this article is highlighted that containers as building elements are “greener than concrete, stronger than wood”. (Paulse, 2010). Concrete has the highest embodied energy in comparison to other construction materials because of the huge volume of cement used. (SCIRO, 2011).

Container architecture also allows sustainable strategies to be developed in a building. Barry Naef who directs the GreenCube Network and the Intermodal Steel Building Unit (ISBU) Association says: “their strength allows the structure to provide green roofs, green walls, solar hot water roofs, all without additional supports”… “It’s hard to do these things on a wood-frame structure”. (Naef, 2010)

Vijayalaxmi concludes his investigation “Towards sustainable architecture – a case with Greentainer” saying that “Steel, per se, has very high embodied energy and therefore not ecological, but here the architect has reused what could have become underused or what could have been a salvaged component. Hence, in this context, the use of steel can be considered as an ecologically sensitive decision.” (Vijayalaxmi, 2010).
4. Thermal performance of ISO shipping containers

The thermal performance of the ISO containers is assessed considering several parameters such as orientation and number of windows, location (London and Madrid), and different building materials (steel, concrete and wood). (Diez Amate, 2013)

Simulations are made using EnergyPlus considering a heating setpoint temperature of 20ºC in the winter period when the room is occupied. The space is considered naturally ventilated in summer. For the location of Madrid mechanical cooling is also considered for the summer period. An ISO container 40 ft HC is analysed with U-values that meet the UK building regulations Part L1B, for new dwellings, dated 2013. Moreover, the insulation used is FRP with a thermal transmittance of 0.22W/m²K which gives a U-value of 0.3 W/m²K for the walls.

The windows selected are double clear glass with 6mm gap with a thermal transmittance of 2.0 W/m²K. Finally, infiltration is accounted as 0.5m³/sm² exchanges per hour.

The thermal performance of an ISO container 40 ft without any treatment or insulation is extremely bad. Thus, the insulation selected for transforming a container into a sustainable building unit is the key point.

![Figure 1: U-values of an ISO 40 ft container without insulation](image)

When ISO containers are transformed into habitable units it is highly important to take into consideration the orientation of the windows placed in the containers. The worse and best window orientations are North and South, respectively, with a difference of around 400 KWh/yr. Tables 2 and 3 show the slightly similar energy performance between containers 20 ft and 40 ft. In yellow is shown the window number and orientation which complies with the UK building regulations. Some limitations exist for the North and East facades regarding the number of windows.

![Figure 2: Energy Performance of a container 40 ft regarding the number of windows and their orientation.](image)

The total energy consumption for the container 40 ft is much higher for the location in Madrid than London. This is due to the climatic conditions in London being milder during...
winter and summer, where containers rely on natural ventilation to maintain the space at comfortable conditions. This is not the case for Madrid as the space is overheating without the use of mechanical systems for cooling. According to Zero Carbon Homes (2009) a maximum of 46 KWh/m²/yr is recommended to comply with an energy efficiency fabric in a detached house dwelling in UK. Consequently the container structure meets the building regulations for two orientations. This is not the case with two and three windows in the North orientation in London. Additionally, according to CTE 2006 in Spain, the average energy consumption for space heating and cooling in new dwellings is around 200 KWh/m²/yr, much higher than the recommended in the UK. Thus, the 40ft container in Madrid meets the minimum values for energy performance recommended in the Spanish regulations. It is important to take into consideration that the minimum U-values considered in the model for the 40 ft container are the ones recommended in the UK regulations.

Results of the thermal performance of different construction walls show that buildings with wooden constructions have lower energy consumption than concrete or steel constructions. Concrete structures are the worst scenario for the three, with a difference in energy consumption of around 500 KWh/yr higher than steel constructions.

5. Conclusions

The container surplus in the Western ports due to the imbalanced international trades finds a solution in container architecture extending the principle of “cradle to cradle” by giving the containers a second use. Also, the price to convert a container into a building element is reduced and therefore affordable compared to the price to melt the steel down to be recycled or the price to produce new steel. Moreover, the container characteristics such as strength, modularity, durability, transportability, flexibility and availability make the use of containers as building elements a valuable and sustainable building construction solution.
Container architecture can also be seen as a regenerator of derelict and depressed areas by providing an economic architectural solution. It offers the possibility to be adapted and easily transported, resulting in a short construction time as well as with the possibility of quickly dismantle. This new emerging architecture can also redefine new social and cultural patterns by transforming the concept of architecture as a way the society expresses its needs.

According to the thermal performance of the container 40 ft analysed in the paper, containers can meet the UK building regulations for energy efficiency in different locations and climate conditions. The type of insulation, number of windows and orientation of the containers will play an important role to be considered as sustainable building units. It has also been shown that containers can perform better than concrete constructions but worse than wooden ones.

Clearly the performance of the container units are strongly dependant on the way they are designed and their envelope insulated, the climatic conditions of the location, the sustainable strategies and active systems including solar thermal applied as well as shading devices and any other passive solution to prevent overheating and minimise heat losses during winter. Moreover, the container architecture can offer an economic, quick to build, comfortable and sustainable solution where common construction methods are not a viable solution.

5. References:
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Naef, B (2010).“Green form the gound up” by Katie Hyslop, Colleen Kimmett, Justin Langille, Monte Paulsen, Christopher Pollon. The tyee solutions series. The tyee.
Energy evaluation of school buildings

Pavla Mocová1, Luisa Brotas2 and Jitka Mohelniková1
1Faculty of Civil Engineering, Brno University of Technology, CZ
mocova.p@fce.vutbr.cz; mohelnikova.j@fce.vutbr.cz
2Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University, UK
l.brotas@londonmet.ac.uk

Abstract
Building energy performance evaluation depends on energy performance indicators as total primary energy, balance of renewable and non-renewable primary energy, total energy delivered into buildings, partial energy supplied for building technical systems for heating, cooling, ventilation, humidity treatment, hot water and artificial lighting. The assessment can also include the evaluation of the thermal insulation of the building envelope, the specification of the average heat transfer coefficient, the energy labelling and finally the specification of the effectiveness of building service technical systems. The optimization of the energy renovation of buildings is based on building cost/performance analysis of sustainability and energy efficiency. The paper presents a study of the energy evaluation of several school buildings in Central Europe. The buildings are representatives of different types of school buildings constructed during the 20th century. The studied buildings are currently energy inefficient. Solutions for the renovation of the buildings in terms of energy savings and indoor thermal comfort are presented.

1 Introduction
Energy efficiency of building is high in the energy and environmental agenda for several countries as a strategy to reduce carbon emissions and minimize the impact in the environment. New standards aiming at sustainable buildings put a strong emphasis on promoting high levels of living comfort while promoting energy efficiency in buildings [1,2]. This is particularly relevant as the existing building sector in the EU is responsible for about 40 percent of the total energy consumption. Modern design buildings with new construction methods can achieve energy savings for heating of more than 90 % compared to the energy use in the old building stock. [4]. A main aim is to promote a comfortable indoor environment with a maximum reduction of the energy consumption. Many existing buildings have acceptable indoor conditions but their energy consumption is too high. It is imperative to promote their renovation [4] aiming for higher energy efficiency and the reduction of CO2 emissions while maintaining or improving the thermal and visual comfort conditions. Renovations are very important mainly for residential and civic buildings with permanent occupancy and high demands for energy consumption for heating, cooling, ventilation and artificial lighting.

2 Energy evaluations in school buildings
The energy balance of several existing school buildings were assessed based on energy audits, and other data available [5], see Fig. 1. for a list of school buildings surveyed. Selected buildings are considered a good representation of school buildings for the last hundred years in the region of the Czech Republic. The studied buildings were sorted in accordance to their location and the site altitude, that vary from 159 to 546 m above see level. The average latitude of the building sites is 50°. The annual average outdoor temperature of the locations is
between 3.3 and 4.4°C. This study is the basis of the assessment of the existing status of the buildings and the energy saving prognosis for an energy efficient renovation.

Fig. 1/1 Photographs of the studied school buildings (building 1 to building 12)
The buildings were constructed in masonry or panel block technology, see Fig. 2.

2.1 Heat losses

The range of heat transmission losses (in %) of the buildings’ envelope are:

- walls: 23.6 to 57.0 %
- floors, roofs: 18.3 to 36.0 %
- windows and doors: 17.4 to 55.3 %

See Fig. 3 for the average heat transmission losses for all buildings studied.

Overall the heat transmission loss of the buildings’ envelope is between 0.76 and 1.33 W.m⁻².K⁻¹. The heat transmission losses of particular components of the buildings’ envelope are:

- peripheral walls: 0.57 to 1.83 W.m⁻².K⁻¹
- roofs and top floor ceilings: 0.36 to 1.50 W.m⁻².K⁻¹
- windows: 2.30 to 3.50 W.m⁻².K⁻¹
- doors: 3.50 to 6.50 W.m⁻².K⁻¹
The average heat transfer coefficient of the building envelope is compared with the average heat transfer coefficient calculated from standard values [6] - required values are valid for newly constructed buildings and recommended for energy efficient buildings, see Fig. 4.

The total heat transmission and ventilation losses of buildings vary from 61.1 kW to 424.5 kW, see Fig. 5.

The factor Area/Volume (A/V) is very important for the evaluation of building losses because it represents the geometrical factor of a particular building. The variation of the geometric shapes and volumes of the studied buildings is presented in Fig. 6. The red line is the A/V factor variation of individual buildings and the blue one is the change of A/V factor of the same volume of the compared building but in the cubical shape (reference cubical shape building).

Fig. 4 The average heat transfer coefficient of the buildings’ envelope compared with required and recommended values

Fig. 5 Heat transmission and ventilation losses of the studied buildings

Fig. 6 The A/V factor of the studied buildings
2 Energy consumption

The total annual energy consumption of the school buildings varies from 265 to 3305 GJ per year. Heating of the building is mostly provided with gas, less by electric heating, infrared radiant panels and hot water heating systems. Data are selected and sorted from energy audits and project documents [5].

The buildings were sorted into volume categories for the energy consumption evaluation as:
- small buildings of volume up to 5000 m³,
- common buildings 5000–10000 m³,
- bigger buildings 10000 – 20000 m³,
- big buildings 20000 – 30000 m³.

Heating in school buildings is mostly from gas boilers. Distric heating from external sources is used in centrally heated residential estates. Old buildings are mainly heated from fossil fuels. Only a few buildings use infrared radiant panels and electric heating systems. The energy consumption is dependent on the building volume and for this reason the total annual consumption of energy in the buildings is between 23.7 and 64.7 kWh.m⁻³ per year and the energy consumption for heating and domestic hot water varies from 19.8 to 61.7 kWh.m⁻³ per annum. See Fig 11.

This study will continue with the specification of optimised renovation variations for energy efficiency and occupancy indoor comfort on selected school buildings.
3 Conclusions
The presented study shows that the evaluated buildings are very energy inefficient. This is highlighted in the comparison of the average heat loss coefficients of the envelope with standards requirements. Building structure and materials are in an acceptable condition therefore the building renovation aiming for energy efficiency should consider the following:
- additional thermal insulation on the building envelope, elimination of thermal bridges,
- window retrofit for better thermal insulation: quality frames and double or triple glass units with low emissivity glazing and insulation gas infill,
- control of air-tightness of the building envelope,
- renovation and regulation of technical installations for heating and domestic hot water, etc.,
- ventilation system with heat recovery,
- optimised daylighting, installation of automatic solar shadings and efficient lighting and light controls,
- installation of solar collectors (thermal or PV), heat pumps or any other active energy system as appropriated,
- use energy saving electric appliances,
- installation of energy saving monitoring systems in the renovated buildings,
- control of the annual balance of energy efficiency, heating cost and ecological impact of building services.

Acknowledgement
Authors would like to thank Ing. Rut Bízková, former Minister of Environment of the Czech Republic for the documentation and energy audits of the school buildings.

References
Air Flow and Thermal Comfort in an Educational Building

Emilia Targońska

1 MSc Low Energy Building Services Engineering, Loughborough University UK, correspondence email e.a.targonska-13@student.lboro.ac.uk;

Abstract
Educational buildings account for a large amount of UK’s non-industrial energy use, while EU set ambitious targets to reduce the energy consumption and carbon emissions by 2020. Thermal comfort in educational buildings is extremely important as it affects productivity of the staff and students. The aim of this research is to investigate thermal comfort and energy consumption in a lecture theatre with natural stack ventilation situated in an educational building. The research is motivated by higher than predicted energy consumption and complaints of the occupants regarding thermal discomfort. Thermal comfort assessment was conducted by physical parameters monitoring and survey questionnaires using Fanger’s approach. A model of the lecture theatre was created using IES-VE software to compare the actual and simulated energy consumption. The results from the experimental data show the dissatisfaction of the occupants could be caused by a high vertical air temperature difference between the head and ankles.

1. Introduction
Educational institutions are responsible for a large amount of UK’s non-industrial energy consumption (IEA, 2004; Barbhuiya & Barbhuiya, 2013). Moreover, the UK has set some of the most ambitious carbon-emission reduction targets (The 2020 climate, 2014). Consequently, the HE sector can play a leading role in the reduction of the UK’s energy use and therefore greenhouse gases (Barbhuiya & Barbhuiya, 2013). However, obtaining energy savings can be difficult limited by the need to maintain a good level of thermal comfort. This is a concern, especially in educational buildings, where thermal comfort is extremely important. Thermal discomfort may create unsatisfactory and disturbing conditions for students and staff and thus reduce their productivity and performance (Barbhuiya & Barbhuiya, 2013). It was shown that productivity is closely related to the level of thermal comfort (Bordass et al., 2001; Leaman 1995).

1.1. Aim of the research
The aim of the research is assessment of the energy consumption and occupants’ thermal comfort in a naturally ventilated lecture theatre.

1.2. Research justification
The study is motivated by the occupants’ complaints regarding the cold environment and general dissatisfaction with the thermal comfort level in the auditorium. However, addressing the problem by changing the heating setpoint from 16°C to 19°C did not satisfactorily improve the thermal comfort and significantly increased the energy consumption. Therefore, there is a need to investigate the ventilation strategies that
could improve the thermal comfort and reduce the energy consumption in the auditorium. This is an important issue due to the ambitious energy targets set by the EU and creating a nurturing for learning environment in educational buildings.

1.3. Objectives

- Thermal comfort assessment by conducting surveys amongst the students in the lecture theatre using Fanger’s approach
- Experimental measurements of the environmental parameters and air flow in the auditorium
- Simulation of the energy consumption in the lecture theatre
- Assessment of thermal comfort improvement and energy-saving strategies

2. Literature review

Thermal comfort can significantly affect one’s productivity, which makes it an important issue in educational spaces (Barbhuiya, 2013). Thermal comfort assessment using adaptive or Fanger’s approach can be used to identify issues in the thermal environment and suggest improvements. Although Fanger’s model was shown to underpredict the actual thermal sensation of the occupants in naturally ventilated spaces (Brager and de Dear, 2000), it has been successfully used for conducting thermal comfort surveys in naturally ventilated educational buildings in UK (Teli et al. 2012; Humphreys & Hancock, 2007) and Europe (Dias Pereira, 2014.; Corgnati et al. 2007; Fato et al. 2004). Results of the investigated studies showed that positioning of the air inlets and direction of the air distribution could reduce temperature gradient and thus improve the thermal comfort in lecture theatres (Sodec, 1986; Linke 1962; Awbi, 1991). The educational sector is facing a challenge of reducing the energy consumption to meet strict requirements set by the EU and UK government (references). Examples of the case study educational buildings show that high energy consumption can be an issue even in naturally ventilated developments (Barbhuiya, 2013; Bunn, 2006; IEA, 2003). Besides the conventional energy saving strategies like setpoint reduction and thermal properties improvement, good control (for example effective use of the BMS system) and monitoring of building’s operation can ensure energy savings (Gupta & Chandiwala, 2007). Moreover, the use of modern dynamic building simulation software allows analysis of the solutions for thermal comfort and energy consumption improvements (Hensen & Lamberts, 2011).

3. Methodology

3.1. Case study building description

The auditorium of the higher education building located in UK is the room on which this research is focused. This 3-storey, 7,920m² building, completed in 2011, is composed of an exposed concrete frame. The building is predominantly naturally ventilated except for the computer labs. The auditorium is an internal room with an area of 166 m² and no external walls or windows. It is naturally ventilated and has a maximum capacity of 148 people. Fresh air is distributed through low-level inlets situated beneath the seats and extracted at the high level through a stack due to the buoyancy driven stack effect (figure 3.1). To minimise the energy use, heating and ventilation systems are controlled by the BMS and will only operate during the school hours and if occupancy is detected by the PIR sensors.
Auditorium’s control strategy
The winter ventilation and heating strategy are temperature and CO₂ level based. Winter setpoint is set as 21°C, but fresh air is supplied to the room at 19°C and is assumed to be heated by the internal heat gains. The summer ventilation is temperature based only and was designed so that overheating criteria are met CIBSE (2006). To assist the cooling process a boost fan, mounted in the top of the stack is used if necessary to extract the hot air and prevent reversed airflow. Night cooling allows the building fabric to cool so it can absorb heat during warm periods on the following day.

3.2. Thermal comfort assessment
Thermal comfort assessment was conducted during the lectures on 7th and 8th May 2014. It involved survey questionnaires using Fanger’s approach and simultaneous monitoring of four basic environmental parameters (air temperature, mean radiant temperature, air velocity and relative humidity). Overall, 191 subjects participated in the experiment (over 50% of the occupants), which can be considered a representative sample size. The survey included the following sections: thermal perception (AMV), thermal comfort, thermal preference, personal sensation, air quality, local discomfort, personal acceptability, personal satisfaction and personal information (clothing insulation and comments). The subjects could indicate, on the attached checklist, the feeling of draught/heat/cold local discomfort in the areas: head, shoulders, arms, torso, back, thighs, lower legs and feet. The students were also asked to mark what they were wearing on the included clothing checklist, later used to calculate the actual clothing insulation rate based on the values given in ISO 7730 (2006). The value of the metabolic rate was estimated as 1.2met which according to ISO 7730 (2006) corresponds to a sedentary school activity. All the instruments used for the measurements were checked and calibrated prior to the experiment (figure 3.2).

Justification for the chosen approach
Although the case study building is naturally ventilated, the use of the Fanger’s approach for the thermal comfort assessment is justified, as the occupants had no control over the indoor environment or the ventilation in the space.

Airflow measurements
Additional measurements involving the supply air temperature and velocity monitoring were conducted to investigate how they could affect the occupants’ thermal comfort. Moreover, to validate the results obtained in May, room air velocity and temperature was also recorded. The measurements were conducted on 8th July during a workshop for 60 students.
3.3. Energy performance assessment
A simplified 3D model of the lecture theatre was created in IES-VE software, based on realistic and exact dimensions. IES Virtual Environment was chosen for this study, as it is advanced and comprehensive simulation software offering high accuracy in predicting a building’s thermal and energy performance. IES was proven applicable software for the modelling of a naturally ventilated building and assessment of its thermal performance (Firth and Cook, 2010). Most importantly IES “has been tested and verified by both ASHRAE and CIBSE” (Nikpour et al., 2013). A base simulation was performed to analyse energy and thermal performance over the year. The model construction, heating and ventilation profiles were designed to recreate the actual conditions accurately. The model was validated comparing the measurement results with simulated values for the 7th and 8th May. Moreover, a series of simulations were carried out to evaluate the effectiveness of the strategies proposed to address dissatisfaction with the thermal comfort and high energy consumption issues. The final simulation involved analysing the results of the final improvement changes proposed.

4. Results and analysis
Environmental parameters measurement results showed the room air temperature during the lectures on 7th and 8th May, despite the varying external conditions, was within the acceptable limits (20.0 °C average), but never reached the recommended minimum summer value for lecture theatres (CIBSE, 2006). Relative humidity and air velocity both remained within the recommended ranges (CIBSE, 2006). The airflow measurements performed on 8th July confirmed the results obtained in May. Moreover, the supply air temperature was observed to closely follow the changes in the external conditions (minimum value of supply air temperature was 16.8 °C). The vertical air temperature difference remained higher than the maximum allowable value of 3K during the last 40 minutes of the workshop creating local thermal discomfort for the occupants (ASHRAE 55, 2004). Highest air velocities were recorded at ankle level. Although the average air velocity remained within the recommended values, it could be unpleasant for the occupants, as even low air velocities are easily detected if supply temperature is low McIntyre (1979).

Thermal comfort assessment revealed that most subjects (24%) voted to feel “warm”. Overall, the votes ranged from “cold” to “hot” which was reflected in the average AMV of 0.1 (“neutral”) and confirmed that thermal comfort is a personal sensation different for everybody (figure 4.1).
Further analysis revealed the lowest AMV votes were given by the occupants seated in the upper central part of the auditorium and near the stack. It was also recorded that the subjects mostly preferred feeling “neutral” and “slightly warmer”. 75% of the occupants were “satisfied” with the thermal environment. On the other hand, over 60% were affected by local discomfort. The feet area was most affected, mainly due to cold. This agrees with the low supply air temperatures and high vertical air temperature difference (between ankle and head level) recorded on 8th July. It is noteworthy, that a vast majority of comments in the last section of the survey were complaints regarding the cold. The indoor environment was often described “too cold to concentrate”. The PMV was found to underpredict the actual thermal sensation of the subjects (-1.0 average PMV) which is in agreement with Brager and de Dear’s (2000) findings as it indicated 70% of students to feel “slightly cool”. However, the number of occupants commenting on feeling colder as the lecture progressed led to the analysis of surveys filled out 50 minutes into the lecture when subjects should have reached the equilibrium with the environment. This showed the average AMV and PMV values were equal (-0.8), suggesting these occupants felt much cooler (figure 4.1). Their preferences changed, as the vast majority preferred feeling “warmer” and fewer were satisfied with the thermal environment.

The energy assessment in the lecture theatre carrying out the base simulation showed that although that while room air temperature during the occupied hours is within the recommended limits (CIBSE, 2006), the electrical energy use (62.4 kWh/m²/year) was better than the benchmark for auditoria (CIBSE, 2012), unlike natural gas consumption rate (126.6 kWh/m²/year).

The thermal comfort assessment and simulation results revealed two main problems needed addressing: local thermal discomfort in the feet area (high vertical air temperature difference) and high natural gas consumption. The effectiveness of the five proposed strategies was investigated. For the thermal comfort improvement, three solutions were tested, which all involved relocating the low-level inlets inspired by Sodec’s (1986) findings. Placing the inlets horizontally behind the seats (in the gap between the rows) was considered most effective. The proposed energy-saving strategies were based on recommendations for energy conservation in further educational buildings (Gupta & Chandiwala, 2007) and findings from previous studies. The supply air temperature was reduced to 18.5°C and the external thermal insulation increased by 35mm. The final simulation compared with the base case obtained marginally lower average indoor temperature, very similar predicted general thermal comfort level. Most importantly, a reduction of the annual natural gas consumption by 15 was noted, proving the implemented energy saving strategies effective (table 4.1).
Table 4.1. Comparison of the energy saving strategies

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Annual Natural Gas Consumption kWh/m²</th>
<th>Energy Savings (compared with base simulation) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Good”/“typical” benchmark (CIBSE, 2012)</td>
<td>21021.4/126.6</td>
<td>17942.6/108.1</td>
</tr>
<tr>
<td>Base simulation</td>
<td>21021.4/126.6</td>
<td>17942.6/108.1</td>
</tr>
<tr>
<td>Final simulation</td>
<td>17942.6/108.1</td>
<td>17942.6/108.1</td>
</tr>
</tbody>
</table>

However, based on the final simulation results, eliminating the main source of the thermal discomfort and Sodec’s (1986) study findings, the proposed strategy is considered to improve the level of thermal comfort.

5. Conclusions

Thermal comfort assessment revealed most subjects voted to feel “warm” on the AMV scale, while PMV was found to underpredict students’ thermal sensation. However, the analysis of the surveys filled after 50 minutes into the lecture, revealed the average AMV and PMV were equal and showed how important is reaching the thermal equilibrium with the environment. High vertical air temperature difference between the head and ankle level was found to be the main reason for occupants’ discomfort. The simulation results showed that natural gas consumption is higher than the “typical” benchmark for auditoria. The final solution proposed, which involved positioning the air inlets horizontally behind the seats, heating setpoint reduction and increasing external thermal insulation, improved natural gas consumption by 15% and is considered to improve the thermal comfort in auditorium.

The use of Computational Fluid Mechanics (CFD) software is suggested to study in detail the effect of proposed inlets relocation on the occupants’ thermal comfort.

REFERENCES


Modelling study: Reducing Grid Emission Intensity in UK Offices while Keeping Occupants Comfortable

Yue Su\textsuperscript{1}, Stephanie Gauthier\textsuperscript{2}

\textsuperscript{1} Bartlett School of Graduate Studies, UCL. Email: yue.su.13@ucl.ac.uk.\textsuperscript{2} UCL Energy Institute, Central House, 14 Upper Woburn Place, London, UK.

Abstract

The need to reduce energy demand at peak time has become one of the priorities in the quest to reduce grid emission intensity. This study focuses on demand side management from office buildings in the UK. Specifically it is developing and testing heating and cooling demand scenarios to reduce emission intensity while simultaneously supporting occupants’ thermal comfort. Design Builder software was used to simulate thermal conditions and energy consumption of four typical office buildings during different operation strategies and for different building fabric improvement following BREEAM guidelines. While applying predictive and adaptive thermal comfort targets with HVAC scheduling developed in the study, results show that HVAC control strategy in off-peak time and enhancement of building fabric can reduce energy demand at peak-time. Electricity intensity is reduced simultaneously as well as carbon dioxide emissions. In addition, with the impact of climate change, the strategy is expected to provide larger benefits in the future.

Keywords: Building energy demand, Thermal comfort, Prediction and simulation.

1. Introduction

Energy used in buildings especially in urban area is becoming a great concern with respect to total energy consumption and environmental impact (Korolijia \textit{et al.}, 2013). Offices and retail spaces are responsible for more than 50\% of the energy used in non-domestic buildings (Lombard \textit{et al.}, 2008). In addition, space heating, cooling and ventilation account for 30\% of electricity consumption in building (Ellies & Mathews, 2002). Thus, strategies aiming to reduce electricity intensity from HVAC systems in office buildings form a significant contribution towards the national commitment target to reduce CO2 emission (CCC, 2008).

A study by Zhang \textit{et al.} (2014) shows that Direct Load Control (DLC) can reduce peak time energy demand by controlling cycling time and levels in AC compressor. This method was applied to different construction types. Various HVAC scheduling methods have been investigated by researchers, including setpoint adjustment, and conventional and advanced scheduling techniques (Haniff \textit{et al.}, 2013).

With regards to office buildings typology, different form-factors have been used in research, including daylit type, ventilation type or energy cost ranges (Crown, 2003). In UK, 67\% of office buildings can be represented by four built-forms, identified as: open-plan sidelit office buildings (OD), cellular sidelit buildings (CS), artificially lit open-plan building (OA), and composite sidelit cellular around artificially lit open plan (CDO) (Korolijia \textit{et al.}, 2013). This classification framework will form the basis of this paper modelling study. The overall aim of this study is to investigate the potential impact of HVAC systems control strategies on...
comfort and electricity intensity in UK typical office building during peak-time. Control of HVAC system uses setpoint and operation time adjustment; thus the control strategies reviewed in this paper will evaluate the potential for switching on and off the system during off-peak time, while guaranteeing occupants thermal comfort in occupied time. These strategies include pre-treating the building in the early morning, and convectional scheduling techniques such as increasing the pre-heating temperature in winter, and decreasing pre-cooling temperature in summer. Strategies developed in study are expected to reduce electricity intensity without much of an increase of overall energy consumption.

2. Methodology

As a whole-building energy simulation (BES) program, this study used DesignBuilder software to simulate the different HVAC systems control strategies. This tool was chosen as it combines the robust EnergyPlus platform and visualisation options (Crawley et al., 2008).

2.1 Model Input

As mentioned before, four office built-forms and associated layout have been selected; see Figure 1 (OD, CS, OA and CDO). The case study buildings comprised of 3-floors. The base-case building construction was set in accordance with heavyweight Part L Notional building database in DesignBuilder. Different options for building fabric were tested; these followed the recommendation of BREEAM Green Guide 2008 for commercial buildings with three categories - A, B and C ratings. These building fabric options focused on internal wall, external wall, insulation, windows, roof construction, ground floor and upper floor construction.

VAV system with heat recovery was used, and zone temperature heating and cooling set point are adjusted to provide better effect of HVAC control strategies. Initial settings are shown in Figure 2 together with occupancy fraction. Manchester weather file was chosen, and tests were conducted based on CIBSE TM33. Table 1 summarises the modelling internal environment settings.
### Table 1 Internal environment settings for office building model.

<table>
<thead>
<tr>
<th></th>
<th>Open plan office area</th>
<th>Cellular office area</th>
<th>Common area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh air ventilation rates[1/s person]</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Lighting target (for artificial lighting)</td>
<td>500</td>
<td>500</td>
<td>200</td>
</tr>
<tr>
<td>Lighting target (for side lit lighting)</td>
<td>400</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>Occupancy density [p/m²]</td>
<td>0.11</td>
<td>0.071</td>
<td>0.11</td>
</tr>
<tr>
<td>Equipment heat gains [W/m³]</td>
<td>15</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Miscellaneous heat gains [W/m²]</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Catering heat gains [W/m²]</td>
<td>0</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>Occupancy metabolic rate [W/person]</td>
<td>125</td>
<td>125</td>
<td>145</td>
</tr>
</tbody>
</table>

### 2.2 Modelling process

For the base case, the four office building types have the same construction. Fabric iterations are first tested on type-OD. The preferred strategies are selected, then all building types (OD, CS, OA and CDO) are compared with different construction ratings.

### 3. Results

Early Switch Off (ESO) and 5-period methods are selected to test with off-peak time operation (Haniff et al., 2013; Escrivà et al., 2010). After many iterations, pre-treatment in off peak time is extended to the whole night treatment (WNE) (from 0am to 8am, and from 6pm to 12pm), and set points are adjusted to the levels shown in Table 2.

<table>
<thead>
<tr>
<th>Set point (°C)</th>
<th>Summer June-August</th>
<th>Mid-season April-May; Oct-Nov,</th>
<th>Winter November-March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>20</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Common</td>
<td>22</td>
<td>23</td>
<td>24</td>
</tr>
</tbody>
</table>

Figure 3 Annual Building energy consumption and thermal comfort comparison for different HVAC strategies.
Figure 3 shows that ESO and 5-period strategies consume more energy than the base case. In particular, 5-period strategy consumes 8% more than ESO strategy, and reduces time in thermal comfort range by 1%. As for WNE strategies, with adjustment of temperature set point, comfort percentage decreases to 82%. Total energy consumption is approximately 1.5 times as much as the base case. Fan turned on during occupied time increases energy consumption by 40%, and time with thermal comfort range by 4%. Finally and increase in temperature set point in summer and mid-season consumes around 40% energy more but only increases time with thermal comfort range by 1%.

Based on these results, ESO and WNE strategies without fan were selected for the final simulations, results shown in Figure 4. In conclusion, ESO strategy consumes similar amount of energy as the base-case, while WNE strategy consumes approximately 1.5 times as much as base-case. From heating and cooling demand shown in Figure 5, it is found that WNE increases cooling energy from 300kWh to 800kWh. However heating energy demand is about 4 to 5 times as much as ESO strategy. Figure 5 also shows the impact of the different layouts and building fabric options.

![Figure 4 Total energy consumption of each type of construction](image)

![Figure 5 Heating and cooling energy consumption of ESO and WNE](image)

In was assumed that heating was from natural gas supply system, whereas cooling was from electricity. Shifts of daytime operation to off-peak period decrease energy intensity especially for electricity. Using a differential tariff such as Economy-7, the price of electricity may be different between peak and off-peak time. Using this framework, the cooling and HVAC operation running cost for the base case and WNE strategy are compared in Table 2. The results are similar to Haniff et al. (2013) predictions, where differential tariff could save around £2,000. Meanwhile, electricity intensity is reduced greatly by less on-peak usage.
However, the total energy cost from HVAC systems is increased, as the cost of heating is £1,000 higher than cooling cost savings.

Table 3 Differential tariff potential saving from cooling and HVAC operation for base case and WNE strategies

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Cooling</th>
<th>Fans</th>
<th>Heat pumps</th>
<th>Heat rejection</th>
<th>Total Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WNE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>£616</td>
<td>£2,093</td>
<td>£95</td>
<td>£86</td>
<td>£2,891</td>
</tr>
<tr>
<td>OA</td>
<td>£634</td>
<td>£2,087</td>
<td>£99</td>
<td>£88</td>
<td>£2,908</td>
</tr>
<tr>
<td>CS</td>
<td>£563</td>
<td>£1,862</td>
<td>£106</td>
<td>£80</td>
<td>£2,610</td>
</tr>
<tr>
<td>CDO</td>
<td>£668</td>
<td>£2,006</td>
<td>£123</td>
<td>£93</td>
<td>£2,890</td>
</tr>
<tr>
<td><strong>Peak time operation (Base case)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>£1,806</td>
<td>£3,155</td>
<td>£164</td>
<td>£307</td>
<td>£5,432</td>
</tr>
<tr>
<td>OA</td>
<td>£1,848</td>
<td>£3,164</td>
<td>£167</td>
<td>£314</td>
<td>£5,493</td>
</tr>
<tr>
<td>CS</td>
<td>£1,361</td>
<td>£2,697</td>
<td>£135</td>
<td>£228</td>
<td>£4,421</td>
</tr>
<tr>
<td>CDO</td>
<td>£1,742</td>
<td>£3,017</td>
<td>£162</td>
<td>£290</td>
<td>£5,212</td>
</tr>
</tbody>
</table>

1 The cost of each strategy shown in the table is from modelled results using construction of Part L Notional standard.

4. Discussion

Results from the study show that buildings with open plan layout consume more energy than building with cellular office for all control strategies. This may be explained by the fact that more energy is used for larger proportion of open-planed offices especially for lighting. This result is similar to the findings from Crown (2003).

Cellular office consumes much less energy for heating and cooling in WNE strategy, as different setpoints may be applied in different zones. Although during occupied time lower heat gains increases heating energy demand in ESO and peak time operation. For WNE strategy, heat gain is only from the HVAC system; while for ESO strategy the heat gain is from solar input, lighting, equipment, occupant and HVAC system. Therefore WNE strategy is some how easier to control and to monitor as independent variables are the weather, the building fabric, and system efficiency. With regards to the building typology, the thermal comfort level is higher in CDO building because partition area of CDO layout is greater than open plan and cellular office, thus more energy can be stored in the building construction elements to maintain stable indoor environment in day time.

Overall ESO and WNE strategies consume more energy than base case operation mode, this result is similar to the finding from Haniff et al. (2013) and Escrivà et al. (2010). As shown in Figure 5, heating is a dominant part of energy consumption compared with cooling demand under Manchester weather condition. This result is similar to finding of the Enterprise and Regulatory Reform (BERR). According to BERR (2008), 49% of total energy consumption in UK is from heating. As heating use natural gas and cooling uses electricity, the impact of WNE strategy on gird intensity is currently relatively small if applied to the entire year. However, space-cooling demand is set to increase in the future, as the predicted energy use by air conditioning in the UK by 2020 is set to reach 20 TWh/y (DTI, 2007). On the other hand, low carbon heat supply is one of the possible drivers for the UK from 2030 to 2050 (Dolman et al. 2012). It is predicted that thermal demand will mainly achieved by electrical heating in the future, which is a significant change compared with current UK market that is dominated by heating from natural gas. Following decarbonisation option, WNE strategy will provide much higher reduction in electricity intensity in the future.
5. Conclusion

This modelling study has applied off-peak time HVAC control strategies for different office buildings typology and fabric. However it was limited to full mechanical ventilation, future studies may explore mix-mode systems. In conclusion, whole night extension (WNE) strategy with temperature adjustment based on seasonal change has been proven to be the most suitable control strategy. Results show that over 80% of occupied time is within comfort level, however the notional building consumes 1.5 times more energy in WNE strategy than in base case strategy. Yet heating and cooling demand is totally shifted to off-peak time when the office building is unoccupied. Electricity intensity is highly reduced as well as carbon dioxide emission reduction. Following increase trend of cooling energy demand as well as electrification of space heating, WNE strategy is predicted to provide much more benefit in reduction of green gas emission and grid intensity.

References


Empirical Study: Investigating the Effect of CO₂ Concentration on Reported Thermal Comfort

Bingyun Liu¹ and Stephanie Gauthier²

¹ Bartlett School of Graduate Studies, UCL, 132 Hampstead Road, London, UK, email: bingyun.liu.13@ucl.ac.uk;
² UCL Energy Institute, Central House, 14 Upper Woburn Place, London, UK.

Abstract
Research shows that an increase in indoor CO₂ concentration stimulates the human respiratory system; this action will in turn increase metabolic rate and heat exchange with the environment. The hypothesis is that people may feel warmer. To investigate this effect, this paper presents the results of an empirical study carried out in climate chamber over the summer of 2014. While the six predictive model independent variables were kept constant, eighteen participants were exposed to three conditions: an increase (1), then a decrease (2) in CO₂ concentration, and finally a constant exposure (3). During the experiments, participants completed questionnaires, reporting on their comfort perception. Results show that CO₂ concentration has an effect on reported thermal comfort. This insight may be used in future studies to review the thermal comfort model and operation of ventilation systems, aiming to reduce energy consumption whilst minimising impact on occupants’ thermal comfort.

Keywords: Thermal comfort, indoor CO₂ concentration, Thermal sensation

1 Introduction

In UK, buildings account for nearly half of the carbon emissions, of which HVAC systems take up the largest part (Perez-Lombard et al., 2008). With increasing demand for comfort in indoor environment, HVAC systems are considered a viable strategy to improve indoor thermal comfort and a primary target to reduce carbon emissions.

Human thermal comfort is usually associated with four environmental factors (ambient air temperature (T_a), mean radiant temperature (T_r), mean air velocity (V_a) and relative humidity (RH)) and two personal factors (metabolic rate (M) and clothing insulation (I_c)) according to ASHARE Standard 55-2013. However, some researchers have pointed out that indoor CO₂ concentration from 600 ppm to 1000 ppm or higher is linked to occupants’ perceptions of stuffiness and discomfort (Persily, 1997). The study presented in this paper aims to identify the potential effect of CO₂ concentration on thermal comfort perception and propose energy-efficient measures whilst minimising impact on occupants’ thermal comfort.

2 Literature review

Results of the study by Kavgic et al. (2008) suggests that cold discomfort complaints increased when indoor spaces are over-ventilated with a lower CO₂ concentration level. Additionally, high CO₂ concentrations in internal environments are associated with poor indoor air quality, increased symptoms of health response, poor cognitive performance (Liu, 2014). Human respiration is one of the important sources of indoor
CO₂ (CIBSE, 2006). During the respiration process, human bodies inhale oxygen (O₂) and exhale CO₂. As metabolic increases, the breathing rate increases and more CO₂ is generated by human respiration (Weissman et al. 1984). Besides, an increase in indoor CO₂ concentration stimulates the breathing rate (Rice, 2003); in parallel a decrease in indoor CO₂ concentration results in a decrease in breathing rate (Sircar, 2008; Leusen, 1954). It can be concluded, that indoor CO₂ concentration stimulates human respiratory system, which will, in turn increase human metabolic rate and heat exchange with the surrounding environment. Hence, the hypothesis is that people may feel warmer when indoor CO₂ concentration increases and people may feel cooler when indoor CO₂ concentration increases.

3 Methods

Over the summer of 2014, an empirical study was undertaken in a climate chamber, six experimental sessions were carried out, and each session required three participants to take part. On the whole, eighteen participants were exposed to three indoor conditions. During the first stage (Stage.1), the participants were exposed to a gradual increase in CO₂ concentration for a period of 30-minutes. The source of CO₂ was the product of four occupants’ respiration (including the researcher) in the fully closed climate chamber. During the next stage (Stage.2), participants were exposed a gradual decrease in CO₂ concentration by opening two vents and the chamber door by 30cm wide, for a period of 30-minutes. Finally during the last stage (Stage.3), participants were exposed to constant low level of CO₂ concentration by fully opening two vents and the climate chamber door, for a period of 30-minutes.

In order to identify the direct effect of CO₂ concentration, the six factors associated with thermal comfort were kept constant during the experiment. Ambient air temperature (Tₘ) was set at 24°C and relative humidity (RH) at 50%. According to CIBSE Guide A (2006), comfort temperature range for air-conditioned buildings in summer is 21-24°C, and relative humidity should be within 30-70%. During the sessions, four Eltek logger GD-47 were used to monitor (Tₘ), (RH) and CO₂ concentration at 1-min interval. Three sensors (S1, S2 and S3) were located at the height of 1.2 m, which is regarded as the breathing zone height of seated participants. The fourth one was located outside the climate chamber. Additionally, an anemometer was placed inside the chamber to monitor the mean air velocity (Vₘ) during the experiments.

Concurrently to the environmental monitoring, participants were required to complete thermal comfort surveys at 10-minutes interval. These aimed to assess participants’ thermal perception and thermal preference in the climate chamber (ISO 10551:2001). Thermal perception was evaluated using the 7-points PMV scale, from -3 (“cold”) to +3 (“hot”). During the experiment, all participants were seated, and asked not to change their clothing insulation level.

4 Results and Analysis

4.1 Environmental Monitoring

This study intended to keep the six factors associated with thermal comfort constant. Clothing insulation and metabolic rate were controlled for. With regard to the environmental variables, monitoring was used to evaluate whether the indoor condition was indeed constant. From the output of the anemometer, (Vₘ) was maintained at 0.05 m/s during the six sessions. As this result is lower than 0.15 m/s, mean radiant air temperature was regarded as equal to ambient air temperature (ISO
variations in CO₂ concentration, air temperature and RH was then reviewed in detail.

Figure 1. The variation of air temperature and CO₂ concentration during Session 1

Table 1. The mean value of CO₂ concentration at each questionnaire interval for six sessions

<table>
<thead>
<tr>
<th>Questionnaire interval</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean CO₂ concentration (ppm)</td>
<td>985</td>
<td>1358</td>
<td>1736</td>
</tr>
<tr>
<td>Increase (ppm)</td>
<td>1117</td>
<td>-799</td>
<td>77</td>
</tr>
</tbody>
</table>

Figure 1 illustrates the monitoring results during the first session; CO₂ concentration increased during Stage.1, decreased during Stage2., and was maintained at a low level (around 1000 ppm) during Stage.3. (T_a) varied slightly throughout the session, from 22.1°C to 23.3°C. Table 1 shows the mean value of CO₂ concentration when the questionnaires were completed at 10-minute interval. CO₂ increased on average by 1117 ppm during Stage.1, decreased by 799 ppm during the next 30 min; and during Stage.3 only increased by 77 ppm. Although openings were fully opened, it was difficult to maintain CO₂ concentration absolutely constant as participants were breathing inside the chamber.

The monitoring results from the three loggers inside the chamber (S1, S2 and S3) are summarised in Table 2. Average (T_a) was within the 21 to 24°C comfort criteria, with a mean value of 22.9°C for the six sessions. Although (T_a) was not absolutely constant, it varied within 1°C roughly, which is within the sensor’s accuracy level of ±0.5°C. Moreover a variation of temperature from 1°C to 2°C should not significantly affect participants’ thermal perceptions (Vargas and Stevenson, 2014). With the small standard deviation of 0.39°C, (T_a) can be considered stable as well as mean radiant temperature. Besides, the difference between the mean temperature recorded by the loggers (around 22.9°C) and chamber sensor setting (thermostat set at 24°C) might be explained by the different sensors’ degree of accuracy, and their locations. In terms of RH, the mean value of the six sessions was 60.1%, which was higher than the 50% set point. This difference might be from the moisture breathed out by occupants. During all sessions, RH varied within the sensors’ accuracy level (±5%), and was always within the 30-70% comfort criteria.
<table>
<thead>
<tr>
<th>Session</th>
<th>Temperature (ºC)</th>
<th>Relative Humidity (%)</th>
<th>Session 1-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>1</td>
<td>22.7</td>
<td>23.3</td>
<td>22.1</td>
</tr>
<tr>
<td>2</td>
<td>23.1</td>
<td>23.5</td>
<td>22.4</td>
</tr>
<tr>
<td>3</td>
<td>22.8</td>
<td>23.3</td>
<td>22.3</td>
</tr>
<tr>
<td>4</td>
<td>22.9</td>
<td>23.2</td>
<td>22.5</td>
</tr>
<tr>
<td>5</td>
<td>22.7</td>
<td>23.1</td>
<td>22.4</td>
</tr>
<tr>
<td>6</td>
<td>22.9</td>
<td>23.6</td>
<td>22.3</td>
</tr>
</tbody>
</table>

4.2 Subjective Assessment: the Effect of CO₂ Concentration on Thermal Comfort

First the relationship between participants’ reported thermal sensation and indoor CO₂ concentration levels is analysed. Figure 2 shows the eighteen participants mean thermal perception value, and the confidence interval (±95%) for each survey time. PMV varied slightly around the “Neutral” category; it rose during Stage.1 from -0.06 to +0.17, and reduced during Stage.2 from -0.28 to -0.50. During Stage.3, PMV did not vary significantly and remain relatively low (min: -0.50, max: -0.39).

![Figure 2. The mean of voted PMV at ±95% C.I. at questionnaire intervals](image)

![Figure 3. The correlation between mean voted PMV and CO2 concentration](image)

The analysis in Figure 3 aimed to identify a relationship between CO₂ concentration and thermal perception. When the coefficient of correlation approaches 1, a strong positive linear correlation can be found between PMV and CO₂ concentration. Hence,
it can be stated occupants felt warmer when CO\textsubscript{2} concentration increased (R=0.99) and occupants felt cooler when CO\textsubscript{2} concentration decreased (R=0.99). For Stage.3, a weak negative correlation can be found; a t-test was carried out to investigate the difference between means of participants’ responses at the start and end of Stage.3. As the P-value was higher than 0.05, there is no significant difference in means of participants’ responses between start and end of Stage.3. Similar t-tests were also conducted between the other survey times, all the P-value were higher than 0.05. Therefore, it can be concluded that occupants’ reported thermal comfort does not change with constant low level of CO\textsubscript{2} concentration.

5 Discussion of Findings

Some of the study’s limitations may affect participants’ responses. For example, the climate chamber looks like a sealed room, which may bring stress and tension to occupants, and not be generally defined as comfortable. This negative impression may affect participants’ psychological state, and then affect their judgement on chamber conditions. Besides, factors such as body weight, sex, age, state of health, food intake and previous activity level have been identified to affect an individual’s metabolic rate (Hoppe, 1993). Since metabolic rate is associated with thermal comfort, participants’ thermal sensations were affected by those individual differences.

The PMV model evaluates human thermal sensation as a function of six independent variables. Results from this empirical study show that CO\textsubscript{2} concentration has some effect on occupants’ reported thermal comfort vote. Therefore CO\textsubscript{2} concentration (C) may be an additional variable, and may also be included in the PMV function as:

\[
\text{PMV} = f(T_a, T_r, V_a, M, I_{cl}, C) \quad (1)
\]

Besides, according to Figure 3, strong correlations between PMV and CO\textsubscript{2} concentration (C) can be found during Stage.1 and Stage.2. Their relationship is predicted as:

\[
\text{PMV} = a_1 C + a_2 \quad (2)
\]

Where \(a_1\) and \(a_2\) are the coefficients the relationship between PMV and \(C\), with:

\[
\text{PMV} = 0.0002 C - 0.2668 \quad (3)
\]
\[
\text{PMV} = 0.0003 C - 0.9178 \quad (4)
\]

However, the study’s limitations discussed above may impact of this relationship. Future studies should apply multivariate regression analysis to identify the relationship between the factors in Equation 1.

Results from this study suggest that controlling indoor CO\textsubscript{2} concentration levels may improve occupants’ satisfaction. In summer, indoor CO\textsubscript{2} concentration level can be lowered by good ventilation and green plants’ photosynthesis process. As a result, occupants may not feel as hot as before when CO\textsubscript{2} concentration decreases. Hence, the HVAC setpoint may be set at a higher temperature in summer. Assuming that in winter occupants prefer not to open windows; the findings suggest that occupants may feel warmer with increased CO\textsubscript{2} concentration, therefore the HVAC setpoint may be set at a lower temperature. However this increase in CO\textsubscript{2} concentration should be low enough not to affect cognitive performance level. By controlling indoor CO\textsubscript{2} levels, the indoor-outdoor temperature difference can be minimised. Potential energy use reduction from HVAC system can be achieved whilst minimising impact on occupants’ thermal comfort.
6 Conclusions

This empirical study investigated the effect of CO₂ concentration on thermal perception by keeping the six factors associated with thermal comfort constant. It concluded that occupants felt warmer with an increase in CO₂ concentration; felt cooler with a decrease in CO₂ concentration; and when CO₂ concentration was kept at a constant low level their thermal sensations did not change. Future studies such as monitoring heart rate variability and measuring the skin temperature at the wrist are suggested. With more accurate monitoring of occupants’ thermal sensation, future research can gain a better understanding of the relationship between CO₂ and thermal comfort. Besides, this study reviewed the thermal comfort model and the operation of HVAC systems, aiming to reduce energy consumption whilst minimising impacts on occupants’ thermal comfort.

References


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Should schools located in polluted areas be naturally ventilated? 
A case study from Chile

Christopher Cáceres-Araya¹

¹ MSc Environmental Design and Engineering, University College London, UK
arqcaceres@gmail.com

Abstract
This paper presents some of the findings of an MSc dissertation on the influence of outdoor pollution on the indoor air quality (IAQ) in naturally ventilated classrooms. The study was carried out in two classrooms in Rancagua (Chile), a city that has high levels of outdoor air pollution. The methodology included a combination of on-site monitoring, an occupant survey and simulations carried out in CONTAM. One of the classrooms was simulated using two scenarios of outdoor PM10 and PM2.5, five ventilation rates (ACH) and no with indoor particulate matter sources. Results show that the ratio between indoor and outdoor concentrations of PM (I/O ratio) tends to be equal to 1 with ventilation rates over 6 ACH. Furthermore, at least 40% of outdoor pollutants could penetrate the classroom even with lower ventilation rates (0.5 ACH). Therefore, the use of natural ventilation may not help to maintain adequate IAQ in schools located in polluted areas and may adversely affect students’ health.

Keywords: IAQ, naturally ventilated schools, particulate matter (PM), CONTAM

1 Introduction

Naturally ventilated buildings have demonstrated their capability to provide healthy and comfortable environments, along with a reduction of environmental impacts by using lower amounts of energy compared to buildings with HVAC systems (Allard 1998; Mumovic & Santamouris 2009). In addition, with the development of natural ventilation techniques over the last twenty years, they would appear to be a suitable option for many types of buildings and, especially those located in template climates (Allard 1998).

Moreover, the challenge of providing good indoor air quality (IAQ) has been addressed through the development of standards and recommendations such as ASHRAE 62 ‘Ventilation for acceptable IAQ’ and CIBSE AM10 ‘Natural ventilation in non-domestic buildings’ that provide guidance for estimating the minimum requirements of air exchange according to the activities performed by occupants in each type of building. Furthermore, these guidelines put emphasis on the fact that, before developing a design, a detailed analysis of the external environment should be carried out to determine if the conditions are suitable for natural ventilation without compromising the occupant’s wellbeing. However, this last point is not always considered when these standards are used as a reference.

An actual example of this situation is the case of Chile’s government, which published a design guide for learning spaces in 2000, as part of the country's most recent educational reform. In particular, the section on natural ventilation encourages the use of cross ventilation in many of Chile’s different climates. However, for unknown reasons, this
document did not consider the fact that Chilean urban areas have high levels of air pollution (MMA Chile 2013). As a consequence, 14 years since the publication of the guide; more than 2,000 new schools were built in Chile (Armijo et al. 2011) using natural ventilation as a suitable option. Therefore, Chilean schoolchildren could be exposed to harmful environments without parents and authorities being aware of this.

1.1 Research aims

In particular, this dissertation intended to provide a picture of the IAQ experienced in a typical naturally ventilated Chilean classroom located in a polluted area. Furthermore, it intended to quantify the influence of outdoor pollution on IAQ as well as exploring the possible effects of poor IAQ on students’ health and learning performance. Some of the questions addressed by the dissertation were:

- How can outdoor atmospheric pollution influence indoor air pollution levels?
- Is natural ventilation a suitable option in environments with high levels of outdoor pollution?
- What type of health effects could those students exposed to high levels of indoor pollution suffer?

2 Methodology

2.1 Scope

Considering the limited scope of the dissertation, the study was focused on the influence of outdoor particulate matter (PM$_{10}$ and PM$_{2.5}$) penetrating the building envelope and carbon dioxide (CO$_2$) generated indoors. Due to time and equipment limitations, the research did not cover other gaseous components naturally present in the air; contaminants from urban sources; volatile organic compounds (VOCs) and other contaminants with harmful effects. Moreover, the study only included the period of the day in which the pupils usually occupied the classrooms. This paper presents some of the findings regarding particulate matter penetration and impacts.

2.2 Case study

The case study focused on two naturally ventilated classrooms in a private school in the urban area of Rancagua. This city is located in the central valleys of Chile, 80 km south of the nation's capital city Santiago. Rancagua’s climate is defined as warm-summer Mediterranean by the Köppen climate classification. A recent report published by MMA Chile (2013) revealed that Rancagua is one of the most polluted cities in Chile. In 2013 Rancagua recorded an annual average concentration of 80 $\mu$g/m$^3$ and 45 $\mu$g/m$^3$ for PM$_{10}$ and PM$_{2.5}$ respectively.

The case study classrooms were attended by male and female students aged between 16 and 19 years old. The classrooms are located in the southeast area of the school, in a two-storey building (reinforced concrete construction without insulation and simple pane windows) which faces two courtyards located on the east and west side. One of the classrooms is located on the ground floor (GF) and the other one on the first floor (1F). Both classrooms have a floor area of 56 m$^2$ (145 m$^3$ volume) and capacity for 36 students and 1 teacher. These spaces are naturally ventilated by cross ventilation and there are no heating or cooling systems and therefore they can be considered as free-running. Moreover, the same group of students uses these classrooms every weekday from 07:50 to 14:20 hours. Figure 1 provides an overview of the classrooms’ layout and main characteristics.
2.3 Study design

The research consisted of three stages:

- The first was a fieldwork study that included on-site monitoring, a physical survey and an occupant survey. The aim of this stage was the gathering of objective and subjective data of the main variables involved in an IAQ study. There was no intervention in the way that the pupils used the studied classrooms, for example, they were free to open and close windows and adapt their clothes as they usually did. The occupant survey requested a personal perception of the indoor environmental conditions and to report possible health symptoms which occurred during the period surveyed. Questionnaires were adapted from previously tested survey form (CBES Berkeley 2014; Engvall et al. 2003). This practice was adopted to reduce the impact that the design of questionnaires could have on the results (Bell 2007; Borgers et al. 2000).

- The second stage was experimental. It consisted of a series of simulations carried out in CONTAM, which considered the data from the first stage as data inputs for the modelling. These models were used to explore the influence of external pollution on the indoor concentrations of PM$_{10}$ and PM$_{2.5}$ according to two hypothetical scenarios of outdoor pollution and ventilation rates.

- Finally, the third stage consisted of a discussion of the measurements and results obtained in the two previous stages in order to answer the research questions.

2.4 Fieldwork

On-site monitoring was carried out between 3 June 2014 and 13 July 2014. This period was selected because it coincides with the highest levels of air pollution for Rancagua every year and is therefore indicative of the worst health impacts. Monitoring included the observation of indoor dry bulb temperature, relative humidity (RH) and indoor CO$_2$ concentrations. Moreover, outdoor variables such as dry bulb temperature, RH, wind...
speed/direction and variations on outdoor PM\textsubscript{10} and PM\textsubscript{2.5} concentrations were monitored from nearby weather/pollutant stations.

### 2.5 Software simulations

CONTAM was used to predict the indoor levels of PM\textsubscript{10}, and PM\textsubscript{2.5} for the classroom that showed the worst IAQ during the monitoring period. Table 1 provides a summary of the range of simulations performed.

#### Table 1 Summary of simulations

<table>
<thead>
<tr>
<th>Group</th>
<th>Outdoor Conditions</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Avg. PM\textsubscript{10} 67 µg/m\textsuperscript{3}</td>
<td>0.5 ACH\textsuperscript{1}</td>
<td>Indoor Temp 13ºC (constant)</td>
<td>36 students</td>
<td>15 ACH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avg. PM\textsubscript{2.5} 45 µg/m\textsuperscript{3}</td>
<td>3 ACH</td>
<td>No indoor sources of PM\textsubscript{10} / PM\textsubscript{2.5}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avg. Ambient CO\textsubscript{2} 600 ppm</td>
<td>6 ACH\textsuperscript{2}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weather Transient</td>
<td>9 ACH\textsuperscript{3}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>Avg. PM\textsubscript{10} 20 µg/m\textsuperscript{3}</td>
<td>0.5 ACH\textsuperscript{4}</td>
<td>Indoor Temp 21ºC (constant)</td>
<td>36 students</td>
<td>15 ACH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avg. PM\textsubscript{2.5} 10 µg/m\textsuperscript{3}</td>
<td>3 ACH</td>
<td>No indoor sources of PM\textsubscript{10} / PM\textsubscript{2.5}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avg. Ambient CO\textsubscript{2} 400 ppm</td>
<td>6 ACH\textsuperscript{5}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weather Transient</td>
<td>9 ACH\textsuperscript{6}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{1}0.5 ACH corresponds to air changes provided purely by infiltration calculated by CO\textsubscript{2} decay method (Chatzidiakou et al. 2014)

\textsuperscript{2}6 ACH corresponds to minimum recommended air changes according to ASHRAE standard

\textsuperscript{3}9 ACH corresponds to minimum recommended air changes according to CIBSE standard

\textsuperscript{4}15 ACH corresponds to recommended air changes according to Chilean standard

The first group of simulations considered 67 µg/m\textsuperscript{3} and 45 µg/m\textsuperscript{3} as outdoor concentrations of PM\textsubscript{10} and PM\textsubscript{2.5} respectively, as these were the average outdoor concentrations registered by weather stations during the period surveyed. A file obtained from Meteonorm 7.0 was employed to run the simulations under transient conditions of temperatures and winds. Moreover, indoor temperature was configured as a constant value of 13 ºC according to the average indoor temperatures in occupied hours. The second group of simulations was run under a hypothetical pollution scenario, which complies with the maximum outdoor concentrations of PM\textsubscript{10} (20 µg/m\textsuperscript{3}) and PM\textsubscript{2.5} (10 µg/m\textsuperscript{3}) stated by WHO (2005) standards. In addition, the indoor temperature was set at a constant 21 ºC, which is more likely to produce thermal comfort considering Rancagua’s outdoor temperatures. This value was defined through the Humphreys et al. (2010) equation.

### 3 Results and discussion

Results from monitoring revealed that the average temperature inside the classrooms was 13°C (GF) and 11°C (1F) for occupied hours. In addition, the occupant survey reported that students felt thermal discomfort, despite over 80% of them stating that they wore high levels of clothing insulation. Moreover, CO\textsubscript{2} monitoring revealed that case study classrooms poor ventilation conditions. The concentrations in both classrooms were above 1100 ppm for more than 60% of the occupied time. Furthermore, occupant survey revealed that 40% of students frequently perceived the air as stale along with 32% of pupils that reported problems of indoor odours. Also, 50% and 25% of students reported sleepiness in classroom GF and 1F respectively. An average of 22.5% of occupants reported difficulties in concentrating, headaches and irritation of the nose.

Figure 2 illustrates simulation results expressed in terms of a ratio between indoor and outdoor concentration (I/O ratio) of PM\textsubscript{10} and PM\textsubscript{2.5} for each ACH tested. Resulting ratios for G1 and G2 simulations were almost identical despite both groups of models being run under different pollution scenarios. This reveals that the pattern of penetration does not
vary significantly with high levels of outdoor pollution. In addition, I/O ratios for both pollutants tend to be equal to 1 at ventilation rates above 6 ACH. These results coincide with findings from a literature review performed by Chen & Zhao (2011). However, comparing resulting ratios for PM$_{10}$ and PM$_{2.5}$, it is possible to see that the pattern of penetration varies according to the size of the pollutant. Simulation results predicted that for a classroom with 0.5 ACH and no indoor sources of PM, the average indoor levels of PM$_{10}$ could be 42% of the outdoor PM$_{10}$ concentration. In the case of PM$_{2.5}$, the indoor concentration could be 52% of outdoor PM$_{2.5}$ average level. In other words, at very low ventilation rates, PM$_{2.5}$ is 10% more likely to penetrate in the classroom than PM$_{10}$.

Figure 2: PM$_{10}$ and PM$_{2.5}$ I/O ratio variation for five ventilation rates

Considering the evidence presented above, it is possible to state that atmospheric pollution has a great influence on indoor air quality of naturally ventilated classrooms in Rancagua, because at the ventilation rates recommended by both CIBSE and ASHRAE standards (above 6 ACH), indoor concentrations of PM$_{10}$ and PM$_{2.5}$ will be almost equal to outdoor levels. Therefore, if the outdoor atmosphere is highly polluted, the indoor environment will also show high levels of air pollution.

In particular, Model 3 (6 ACH and current levels of pollution in Rancagua) predicted an average indoor PM$_{10}$ $55.7 \pm 8.7$ µg/m$^3$ and PM$_{2.5}$ $39.9 \pm 4.4$ µg/m$^3$. Such levels of pollution were qualified as ‘relative high’ by Fromme et al. (2005), who found similar indoor concentrations of particulate matter in a study carried out in smokers’ apartments and nursery schools in Germany. In addition, Indoor PM$_{2.5}$ concentration predicted by Model 1 ($24.2 \pm 5.5$ µg/m$^3$) is similar to the levels that Janssen et al. (2003) linked with conjunctivitis, hay fever, itchy rash and sensitisation to outdoor allergens.

4 Conclusion

This dissertation aimed to assess the impact of a polluted outdoor environment on the classroom’s IAQ as well as to discuss the suitability of using natural ventilation strategies to provide fresh air. Furthermore, the adverse effects of PM$_{10}$, and PM$_{2.5}$ and CO2 indoor concentrations on students’ health were explored. Due to space limitations simulations results for CO2 were not presented.

The study was conducted in two naturally ventilated classrooms located in the urban area of Rancagua (Chile), a city that typically has high levels of PM$_{10}$ and PM$_{2.5}$. In both classrooms students reported thermal discomfort and dissatisfaction with IAQ which can be linked to the low average indoor temperatures (13°C and 11 ºC) and low ventilation
rates. In addition, a significant percentage of students reported feeling sleepiness. Other symptoms such as difficulties concentrating, headaches and irritation of nose were reported by around 20% of pupils.

Monitoring data was employed to build a base model in CONTAM. The model was tested under two hypothetical scenarios of outdoor pollution and transient weather conditions in order to predict the indoor concentrations of PM₁₀, PM₂.₅ for five ventilation rates. Subsequently, results from 10 models were analysed and compared with relevant research.

In classrooms naturally ventilated by cross ventilation, regardless of outdoor PM₁₀ and PM₂.₅ levels and with the increase of ventilation rates, the proportion between indoor and outdoor concentration (I/O ratio) tend to be equal to 1 for both pollutants. Therefore, if the external environment is highly polluted and the classroom is naturally ventilated by cross ventilation, the indoor PM concentration will be high even at ventilation rates below ASHRAE (6 ACH) and CIBSE standards (9 ACH).

Simulations predicted high indoor PM₁₀ and PM₂.₅ for all models run under an outdoor concentration of PM₁₀ 67 µg/m³ and PM₂.₅ 45 µg/m³ (Rancagua’s average PM during monitoring period), especially for those with high ventilation rates. In addition, Model 1 (0.5 ACH), which simulates pollutants' penetration purely by infiltration, recorded an average indoor concentration of 28 µg/m³ and 24.2 µg/m³ for PM₁₀ and PM₂.₅ respectively. A previous research linked similar indoor PM concentrations with conjunctivitis, hay fever, itchy rash and sensitivity to outdoor allergens.

5 References


CBES 2014, Occupant IEQ survey. University of California Berkeley


MMA Chile, 2013. Primer Reporte Reporte del Estado Estado del del Medio Ambiente Ambiente


Plug Load Consumption in Typical Commercial Offices in India

Mithi Dave¹ and Rajan Rawal²

1 M.Tech Climate Change and Sustainable Development, CEPT University, India, mithi.dave@cept.ac.in ;
2 Centre for Advanced Research in Building Science and Energy, CEPT University, India, rajanrawal@cept.ac.in

Abstract
The increasing penetration and diversity of plug loads and their ubiquitous nature in work environments in India means that they are potentially significant consumers of electricity. End-use energy efficiency measures in buildings have largely ignored plug loads which might be attributed to a dearth of India-specific studies which quantify plug-load energy consumption and their usage characteristics through end-use measurements. Field studies in 30 typical offices covering a total floor space of 8000 m² and 1160 plug loads were carried out to find plug load consumption characteristics. The study shows plug loads as significant consumers of electricity and reveals wide gaps in design and actual on-site provision for these loads that need to be addressed. The study also quantifies the contribution of standby power from major plug loads found in offices.

Keywords: plug loads, measurements, end-use, offices, standby power

Introduction
The commercial building sector in India is growing at a rate of 9% every year (Kumar, et al., 2010) which has in turn contributed to a huge demand in office spaces. It is estimated that approximately 5.1 million square meter of more office space is required every year to meet the growing demand (Kumar, n.d.). Though the energy required per unit area of floor space in India’s commercial buildings has remained low compared to those in developed countries, the scenario has been changing with more demands of offices that meet international standards.

There is a lack of empirical studies in India which quantify consumption of plugged office equipments during office hours as well as standby power after office hours. Prediction of plug load usage is difficult which makes it important to have field studies which quantify their consumption characteristics. Lack of reliable data or the assumption that plug loads are not major contributors to building energy consumption could be the reason that end-use energy efficiency measures and building energy efficiency codes have not integrated provisions for plug loads. Also, at the design stage, electrical consultants tend to assume connected loads of plugged office equipments on the basis of number of occupants and a general understanding of individual and shared equipments used by them. This study tries to compare the designed load versus connected load as well as with the on-site provision for loads through presence of plug sockets.
Methodology

Typical offices in India have automated work processes with office electronics being an indispensible part of office environments. They have single working shifts with average 8.1 working hours (OECD, 2011). 30 such commercial offices of size ranging from 65 m² to 883 m² were chosen. A wide range of businesses included IT, finance and banking, design, engineering, urban planning, logistics, sales and marketing and education consultants.

The purpose of data collection was to find out types of plug loads used, their energy consumption and their power state after office hours. As much as possible, surveys were done just before office closing time so that the power states after office hours could be recorded after employees had left. In offices where it was not possible to survey after office hours, users were asked to mention the after-hours power state of their office equipments and relevant people were asked about the after-hours power state of shared devices. Data collection involved:

1) A walkthrough of offices counting plug points, making an inventory of connected plug loads and noting their after-hours office status.
2) Instantaneous metering of plug loads to find out their power consumption as well as their power factor using a plug-in meter (Meco PowerGuard09H).
3) Interviewing the relevant people on device usage hours, other factors required to calculate plug load energy consumption, office area, utility bills etc.

Table 1 shows the list of inventoried equipments. Not all devices that have been inventoried have been metered or their energy consumption accounted for in the final results. The reason is that these devices were either present but not used, were very rarely used or when it was difficult to estimate the active usage hours (E.g. It is difficult to estimate usage time for scanners and coffee makers).

<table>
<thead>
<tr>
<th>Information and Communication Technology Equipment</th>
<th>Miscellaneous Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Refrigerators</td>
</tr>
<tr>
<td>Monitors (LCD and CRT)</td>
<td>Water coolers</td>
</tr>
<tr>
<td>Laptops</td>
<td>Water Purifiers</td>
</tr>
<tr>
<td>Printers (Laser, Thermal Inkjet, Dot-matrix)</td>
<td>Coffee Makers</td>
</tr>
<tr>
<td>Scanners</td>
<td>Plugged Fans</td>
</tr>
<tr>
<td>Fax Machines</td>
<td>Desk Lamps</td>
</tr>
<tr>
<td>MFD (Laser and Inkjet)</td>
<td>UPS</td>
</tr>
<tr>
<td>TV (LCD and CRT)</td>
<td></td>
</tr>
<tr>
<td>Projectors</td>
<td></td>
</tr>
<tr>
<td>Network Switches</td>
<td></td>
</tr>
<tr>
<td>Radio</td>
<td></td>
</tr>
</tbody>
</table>

The standard IEC 62301 defines standby power as ‘the minimum power draw of the device while connected to the mains’ (Meier, 2005). It refers to the minimum power consumed by devices when they are not performing their primary function. Many electronic devices need to maintain auxiliary capabilities like receiving a remote signal (E.g. TV or printers) or powering a clock. All devices using external AC-DC power supplies consume small amounts of power even though they are essentially off. This study includes energy consumed by plug-loads while in the active mode (performing their primary functions) and while being on standby. The monthly energy consumption calculation methodology is shown in Figure 1.
It is difficult to estimate energy consumption of plug loads like water coolers and refrigerators based on power usage due to the presence of components like compressors which do not remain on all the time even though the plug load is technically on. Energy consumption for refrigerators has been calculated on the basis of methodology provided in the Home Energy Saver Project (LBNL, n.d.). Average consumption of a water cooler was taken on the basis of annual consumption values provided by (Rivas, 2009). The number of prints issued by printers in a given time interval was taken as a basis for calculating their energy consumption.

**Results**

To explore the possibility that consumption patterns might differ according to office size, the results were divided into four area bands of offices. In Figure 2, as the offices size increases, the number of occupants increases. But the occupant density in the larger offices is lower. This could be because in larger offices common spaces like corridors, reception areas, conference rooms etc were found more often than in smaller ones. Energy Performance Index (EPI) of the plug-loads showed a very strong correlation to occupant density (Figure 3), which might not be true for other electrical loads in the offices.

The average consumption contribution of electrical energy from plug-loads in offices ranged between 6.1% and 19.5% for different office sizes (Figure 4). Due to the strong relationship
between plug-load consumption and occupant density, the contribution from other loads like lighting and air-conditioning starts to increase in the larger offices.

Due to individual usage, the number of computers was largest among plug-loads, followed by printers and multi-function devices (MFDs) which are usually shared among a group of individuals. Loads like refrigerators, water-coolers, televisions, projectors and fans are shared by even larger groups of people and hence their number and density was the lowest. Figure 5 shows the energy consumption contribution of different equipments. As number of miscellaneous loads like refrigerators and water-coolers remain the same whether there are 5 or 20-25 people, their total contribution reduces in larger offices.

Table 2: Power Consumption of Equipments

<table>
<thead>
<tr>
<th>Name of Device</th>
<th>Active Power (W)</th>
<th>Standby Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>68.8</td>
<td>2.5</td>
</tr>
<tr>
<td>LCD Monitor</td>
<td>18.3</td>
<td>0.8</td>
</tr>
<tr>
<td>CRT Monitor</td>
<td>52.1</td>
<td>3.0</td>
</tr>
<tr>
<td>2-in-1 Computer</td>
<td>58.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Laser Printer</td>
<td>373.3</td>
<td>8.4</td>
</tr>
<tr>
<td>Thermal Inkjet Printer</td>
<td>20.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Dot-matrix Printer</td>
<td>33.7</td>
<td>13.9</td>
</tr>
<tr>
<td>Laser MFD</td>
<td>509.5</td>
<td>22.3</td>
</tr>
<tr>
<td>Thermal Inkjet MFD</td>
<td>15.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Projector</td>
<td>213.3</td>
<td>2.6</td>
</tr>
<tr>
<td>TV</td>
<td>64.4</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 2 shows the power consumption of equipments in active and standby mode. While in the case of computers newer technologies like LCD monitors and 2-in1 computers consume much lesser than their older counterparts (LCD monitors consumes 65% lower than...
CRT monitors), laser printers consume almost 95% higher than thermal inkjet printers which have older technology. Dot-matrix printers have one of the highest standby powers. Figure 6 shows how much equipments would consume if they are allowed to remain on standby after office hours. In this case more than 93% of the energy consumed by printers and MFD in a single day is while being on standby. The average contribution of standby power to total plug load consumption in all offices was around 2%.

Power factor (PF) is a measure of the efficiency with which a load draws current from the source. Higher the PF is, better is the efficiency. The devices in Figure 7 use AC-DC power supplies which draw more current than required. As power losses are proportional to the square of the current drawn, the losses would get quadrupled if the current drawn doubles. Hence it is important to have good PF for devices. The PF of most equipments is not good in active mode while in standby it goes even lower.

At the building design stage, connected load through plugged devices is calculated by making assumptions on individual and shared usage of certain typical plug-loads found in offices. Through discussions with design consultants, it was concluded that consumption of around 120W per occupant is assumed. When this was compared with actual connected load, both values were found to be very close (Figure 8). Considering the large number of unused plug sockets that were found in the offices, the designed and connected loads were compared to the on-site load provision. Figure 8 shows that the on-site provision far exceeds the other two. This shows the large gap between requirement and provision. Though flexibility is required, too much extra provision might become an incentive to consume much more than required.

**Conclusions**

This study helps to establish a case for plug-loads as a potential area for energy management in buildings.

Energy consumption of plug-loads is closely related to occupant density and their contribution to the total electricity consumption is significant especially in high density offices. Offices with floor space between 100 m² and 300m² were the densest offices in the sample with 1.2 occupants/10m². Average plug load contribution to the total electricity consumption in these offices was as high as 20%.

Many users do not switch off their computers completely at the mains before leaving office. There is an even higher probability of shared devices like printers and MFDs of remaining on
standby after office hours due to lack of individual ownership. The study shows that around 7-8% of the daily energy consumption of individual CPUs and monitors and as high as 93.4% of that of printers and MFDs would be due to standby power if they are allowed to remain on standby after office hours. Though the average contribution of total standby power is low (2%), it would help to introduce practices to reduce it further or keep it from growing in order to avoid large scale aggregate consumption at the national level.

There is scope for improving power factor of plug-loads. The problem of low power factors can be addressed through policies. In Japan and European countries, electronic items with more than 75W need their harmonics to be reduced mandatorily. This means that manufacturers have to correct power factors before sale in these countries (Fortenbery & Koomey, 2006).

The average load factor for offices in all four area bands was between 6.96W/m² and 15.45W/m² which correspond to the set of offices with lowest and highest occupant density in the study. These are comparable to ASHRAE load factors of 5.4 W/m² and 16.1W/m² for light and medium/heavy load density of offices (ASHRAE, 2009). The provision for plug loads far exceeds the design and the actual connected load. This gap must be addressed.

This study is a first step towards understanding consumption of plug-loads. More long-term continuous monitoring is required to get a better picture.

References


Do the new sustainable schools in the UK achieve optimum lighting design? Hatfield Community Free School (HCFS) A case study

Zinah Noori¹ and Tim Coleridge²

² MSc Architecture: Advanced Environmental & Energy Studies, head of programme and supervisor, Centre for Alternative Technology (CAT), e-mail: tim.coleridge@cat.org.uk

Abstract
This paper assesses the lighting design of a recently built sustainable school, Hatfield Community Free School, against a benchmark that represents a best lighting practice. The school chosen for the case study was built in 2011 and achieved a provisional BREEAM rating of ‘Very good’.

The methodology used involved accumulating data from the literature to develop an assessment checklist (Secondary research), followed by field measurement against the requirements of the checklist (Primary research). The criteria for data collection are based on Health & Wellbeing (H&W) and Energy Efficiency (EE) under which sub headings are introduced: functional and inspirational.

The results reveal that the lighting system of the case study does not comply with the requirements of best practice. It is recognized that aspects within BREEAM credit criteria do not necessarily achieve optimum solutions. This is mainly due to BREEAM focus on functional and energy efficiency requirements without addressing the inspirational aspects of lighting.

Key words: BREEAM, Lighting, Energy efficiency, Health & Wellbeing

Introduction
Successful lighting design contributes to factors which go far beyond the functional requirements of task performance and involve features related to people’s health, appearance of the space and environmental concerns (Bella, L. Bisegna, F. Spada, 2011). Functionally, students and staff are required to view their tasks effortlessly and accurately (CIBSE:SLL, 2012). People’s health can be affected when they are subject to glaring and flickering conditions (DfEE, 1999). Successful spatial appearance with brightly lit surfaces and an interesting effect of light and shade can promote stimulating and pleasant learning spaces (CIBSE:SLL, 2011). From an environmental point of view, primary schools are responsible for one third of UK total carbon emissions (CIBSE:SLL, 2011). The aim of this study is to find out how far newly built schools may be from the objectives of best practice lighting guidance. The study focuses on teaching spaces (Classrooms).
The Case Study: Hatfield Community Free School (HCFS)

**Location:** Hatfield, Hertfordshire  
**School type and capacity:** Primary/420 pupils  
**Site area:** 22,390m²  
**Building area:** 2,242m²  
**Cost:** £5.6 million  
**Classrooms number & area:**  
18 facing west, south and east. Area: ~60m²  
**Classrooms assessed:** 2 samples, one facing east (Cl.1) and one facing south (Cl.2). Both are typical in size and design.  
**Classrooms’ specification:**  
**Walls:** white painted with sink wall painted in green.  
**Floors:** dark brown carpet, mushroom color vinyl for the sink area.  
**Ceiling:** white acoustic tiles.  
**Main Furniture:** Maple laminated wood for student tables, computer benches and other storage units.  
**Light Fittings:** 3 rows of compact fluorescent luminaires, recessed module type with downward light distribution. Lighting control system comprised of manual switching on/off, occupancy detectors and automatic daylight dimming.

The school is one of the newly built sustainable schools, built in 2011. Its sustainability level as assessed under the BREEAM scheme, is given a provisional rating (design stage) of ‘Very good’. The school is single story and has a unique site character; it is located in a broad, plain area within a low-rise residential area. Air pollution is within the government set limit, multiple green areas surround the building. This kind of non-distributing external environment is an advantageous in providing maximum daylight for all its spaces.

**Methodology**

The method involves accumulating data from the literature (Secondary Research) and from field measurements (Primary research).

1. Secondary research (Literature review): The researcher analysed multiple types of sources associated with school developments. The final product of the desktop study was an assessment checklist comprising two main criteria: Health & Wellbeing (H&W) and Energy Efficiency (EE). These in turn were expanded further into nine aspects, each of which entailed key questions for compliance. The final checklist comprised 40 questions. Question numbers were used to identify the level of compliance (See figure 2). The two principles of H&W and EE in BREEAM methodology have also been investigated. Details of the school’s BREEAM credits for lighting were not explored, as the final report had not been released by the time of the assessment.
2. Primary research (Field measurements): Responding to the checklist required visual and practical surveys, which were carried out during October and November 2013. The measurement of daylight factor (DF) for both sample classrooms was made on the 14th of October; the main weather condition was cloudy. Sky illuminance was between 3,540-21,400 at 10:00 and 11:30 respectively. Electrical light measurements were implemented under internal temp. 17°C (Fig. 4).

Results
The findings of the assessment of the two classrooms showed similar results. The graph in figure 5 illustrates the gap between the level of optimum lighting solution (Red line) and the level found in practice (Grey line). Problematic features within the two main aspects H&W and EE were identified. With regards to H&W, the gap was mostly related to glare problems (Functional aspect); insufficiently lit surfaces and in appropriate choice of blinds that entirely block the view to outside (Inspirational aspects). EE findings revealed that saving in energy could be achieved if spaces had better distribution of daylight and more efficient lamps. Lack of implementation of maintenance procedures, due to cost concerns, was also identified in relation to the annual cleaning of luminaires and internal surfaces. Such underperforming maintenance measures can affect the illumination level and efficiency of energy usage in classrooms.
Fig. 5 Analysis of the gap between best practice solution and the employed one
Colour Code: Aspects written in **Red** are the ones addressed by optimum practice tool only (Not BREEAM)

Fig. 6 - The bold value is for the optimum reflectance level.

Fig. 10
On/Off switching for the first Row of luminaires
**BREEAM lighting features and Best practice aspects**

To improve our understanding of the gap shown in fig.5, a comparison between the aspects of the two tools is important, given that the school is designed to achieve ‘Very good’ BREEAM rating. The table below (Fig.11) is based upon all six aspects of lighting design considered within BREEAM, which are mainly related to Health & Wellbeing. The scope of its energy efficiency is addressed within the overall assessment through energy/CO$_2$ credits. This side-by-side comparisons between the

<table>
<thead>
<tr>
<th>BREEAM aspects and compliance conditions</th>
<th>Best practice aspects and compliance conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Daylight Delivery</td>
<td>EE) Daylight as a dominant light source</td>
</tr>
<tr>
<td>1. (2%) daylight factor with uniformity level of 0.3-0.4 Or shy view + Requirements of (space proportion, window height, surface reflectance at the back of the room)</td>
<td>1. (2%) daylight factor with uniformity level of 0.3-0.4</td>
</tr>
<tr>
<td>2 Glare Control:</td>
<td>H&amp;W) Glare &amp; Velling reflection</td>
</tr>
<tr>
<td>1. Shading solutions that do not affect lighting energy usage</td>
<td>1. Shading ensure daylight provision</td>
</tr>
<tr>
<td>2. Shading that is not a source of glare</td>
<td>2. Task position in relation to windows</td>
</tr>
<tr>
<td>3. Task position in relation to windows</td>
<td>3. Illuminance variation for artificial light (0.8)</td>
</tr>
<tr>
<td>4. Contrast between inside and outside brightness</td>
<td>4. Contrast between inside and outside brightness</td>
</tr>
<tr>
<td>5. Glare factor for furniture fittings</td>
<td>5. Glare factor for furniture fittings</td>
</tr>
<tr>
<td>6. Velling reflection on computer screens and white board controlled through task arrangement</td>
<td>6. Velling reflection on computer screens and white board controlled through task arrangement</td>
</tr>
<tr>
<td>3 View Out:</td>
<td>H&amp;W) View</td>
</tr>
<tr>
<td>1. Maximum distance from windows (7m)</td>
<td>1. Window proportion (20%) of wall area</td>
</tr>
<tr>
<td>2. Minimum window proportions of 20% of wall area</td>
<td>2. Window position</td>
</tr>
<tr>
<td>3. Window width proportion</td>
<td>3. Window width proportion</td>
</tr>
<tr>
<td>4 Internal lighting:</td>
<td>H&amp;W) Illumination level</td>
</tr>
<tr>
<td>1. Illumination level of classrooms is according to the standards</td>
<td>1. Local illumination is according to the standard level</td>
</tr>
<tr>
<td>2. Illumination level for the requirements of computer screens based on luminance of the lighting fittings and illumination level of the surrounding surfaces.</td>
<td></td>
</tr>
<tr>
<td>5 High frequency lighting:</td>
<td>EE) Lamps &amp; Equipment</td>
</tr>
<tr>
<td>1. Fitting of high frequency control gears</td>
<td>1. Fitting of high frequency control gears</td>
</tr>
<tr>
<td>2. Performance of lamps &amp; equipment incuding LDR of luminaries and lamp efficacy</td>
<td>2. Performance of lamps &amp; equipment incuding LDR of luminaries and lamp efficacy</td>
</tr>
<tr>
<td>5 Zoning and occupants’ controls:</td>
<td>EE) Lighting controls</td>
</tr>
<tr>
<td>1. Switching for indoor lighting zoned according to window area and teaching activities (White board demonstration area)</td>
<td>1. Zoning according to window zone</td>
</tr>
<tr>
<td>2. The use of absence detectors and dimming control for window areas, as specified in CIBSE, in 2011</td>
<td>2. The use of absence detectors and dimming control for window areas</td>
</tr>
<tr>
<td>3. Switching that are user friendly</td>
<td>3. Switching that are user friendly</td>
</tr>
<tr>
<td>Separate lighting for teaching activities is addressed within illuminance, variation, employment of multi lighting system (Aspect 3 item 5 in figure 10)</td>
<td>Separate lighting for teaching activities is addressed within illuminance, variation, employment of multi lighting system (Aspect 3 item 5 in figure 10)</td>
</tr>
</tbody>
</table>

Figure 11 – A comparison between BREEAM and the best practice lighting aspects

Colour Code: **Blue**-Similar compliance conditions, **Red** & **Light blue**-Addressed in a different way, **Black**- Not addressed

two aspects helps identify how most of the unaddressed aspects in BREEAM are related to inspirational features (See figure 12). The graph in fig.5 (Page 4) also shows the missing BREEAM features (written in Red) within the identified gap of performance.

<table>
<thead>
<tr>
<th>Aspects of best practice not addressed in BREEAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 H&amp;W (Function)- Lighting quality</td>
</tr>
<tr>
<td>2 H&amp;W (Inspirational)- Illumination type</td>
</tr>
<tr>
<td>3 H&amp;W (Inspirational)- Space architecture, Modelling, Illumination variation;</td>
</tr>
<tr>
<td>2 Appearance of internal surfaces (Brightness)</td>
</tr>
<tr>
<td>3 Luminaires appearance in respect of space architecture</td>
</tr>
<tr>
<td>4 Modelling requirements</td>
</tr>
<tr>
<td>5 Employment of multi lighting systems</td>
</tr>
<tr>
<td>4 EE- Daylight as a dominant light source</td>
</tr>
<tr>
<td>5 EE- Efficient light equipment</td>
</tr>
</tbody>
</table>

Figure 12 Summary of BREEAM features that are not addressed in BREEAM
Discussion:
The findings of this study revealed that the lighting design of the case study school (HCFS) is not optimum. The lighting system is designed to achieve BREEAM ‘Very good’ rating, as a minimum requirement of BSF programme. However, the assessment findings concluded that the lighting aspects within BREEAM method would not be recognized as best practice. The biggest gap was found within Health & Wellbeing, where inspirational aspects in relation to features that promote space appearance can influence the psychological effect of the building on its users. The findings also revealed the protection approach of BREEAM, it aims to ensure comfortable visual conditions for occupants (by controlling flicker and glare), as well as reducing carbon emissions from electrical power usage. The BREEAM mechanism to ensure efficiency of lighting equipment is also recognized as incomplete.

The current literature and lighting standards give guidance on all design features, with no obligatory requirements for practicing (CIBSE, 1994). The research in this paper suggests that achieving an optimum lighting solution requires consideration of all lighting aspects as one package. As an example, the provision of light fittings, for instance, that integrate well with the form of the space yet cannot contribute to the illumination of the ceiling, which is one of the important surfaces, means that the solution can not deliver best lighting practice.

Conclusion:
The findings of this study indicate that BREEAM, as an assessment method, is required to include additional aspects within the Health & Wellbeing to achieve optimum lighting solutions in schools. The provision of an inspirationally lit study environment is important in enhancing teachers and pupils’ motivation and performance and is also a requirement within the current education guidelines.

The researcher recognizes that in order to properly answer the topic question, it would be necessary to assess more than one sample school. Following generalization of the results more lessons can be learned and disseminated across the building industry profession.

References:
Analysing factors that contribute towards making hotel energy efficient and sustainable

Gaurav Shahane

MSc Sustainable Design and Building Performance, Oxford Brookes University, Oxford, UK, 13004681@brookes.ac.uk

Abstract

This research investigates the different aspects, which make a hotel energy efficient and sustainable. Base case of a hotel in Oxford UK is studied, on which Post Occupancy evaluation is carried out to understand the functionality of the hotel with respect to its users while the building design tool IES is used to understand what strategies can be followed in order to make the existing hotel energy efficient. The strategies analysed are based on the design, management and the customers’ attitude towards green hotels. The aim is to derive an optimum retrofit and environmental management solutions for existing hotels helping to reduce energy consumptions.

The initial conclusions are that significant amount of energy can be saved if the management is trained towards technical and organizational activities which reduce the negative impacts of the hotel on the environment due to its operational activities. Refurbishing old hotel buildings with updated technology, energy efficient products saves energy expenditure. Hotels can use green strategies as a marketing tool, thus influencing the customer to pay for the green facilities.

Keywords: Hotels, Hotel Management, Customer attitude, Energy Efficiency

Background

Tourism is one of the largest and rapidly growing industry among various industries in the world, which improves the economy by bringing in job opportunities, also improving the understanding of foreign cultures, preservation of cultural and natural heritage and infrastructural investments. While it brings social, cultural and economic benefits, it also has adverse effects on people’s lives and on the environment (Mathieson A 1982) Tourism influences natural and man-made environment and may involve activities that can have negative environmental effects. Many of these impacts are related to the construction of infrastructure facilities like roads, airports and tourism facilities like resorts, hotels, restaurants and shops. The negative impact of tourism development can gradually destroy the environmental resources on which it depends: it can cause destruction of habitats, degradation of landscapes as well as competition for scarce resources and services, such as land, fresh water supply, energy and sewage treatment. (www.uneptie.org n.d.) On the other hand tourism has the potential to contribute towards environmental protection and also to
conserve it. This is possible if environment and all the aspects of tourism are integrated. (Marco Beccali 2009) The research deals with the tourism facilities like hotels and resorts which impact the energy use, and increase the carbon footprint of the particular tourist destination. It discusses the different aspects of the hotel industry, which contribute towards impacting the environment and ways by which it can be reduced.

Introduction

The two major concerns of 21st century are energy and environment, as burning fossil fuels emits greenhouse gases, which not only pollute the environment but also contribute to global warming. The over use of fossil fuel reserves has lead to depletion of these resources, which has further led to the use of alternative energy resources and improving energy efficiency in various fields. Commitments made by the international community to address these environmental concerns, such as Kyoto Protocol and can be realized with efforts from all sectors of an economy, especially that energy intensive ones, of which hotels are major contributors. (Wu Xuchao 2010)

Hotels are multifunctional buildings and provide exclusive amenities and services to guests. They consume substantial quantities of energy, water and non-durable products to attract costumers. The low resource efficiency starting from the building design to the end-users in hotel facilities results in environmental impacts and is greater compared to commercial buildings. (Sozer 2010)

Research Question

What are the various factors that affect the energy performance of the hotel and how can the existing hotels be made sustainable?

Aim

The aim of the research is to identify the different aspects of the hotels, which consume more energy than required in order to propose strategies, which can reduce the impact on environment.

Sustainability in Hotels

Hotels are the buildings types which make up to 5% of a nation’s building stock (Bohdanowicz et al.,2004), but globally hotel industry comprises more than 300000 facilities making it a major sector in the tourism industry (Olsen et al., 2000). Catering to number of tourists, the resource utilization of hotels is more and hence its environmental footprint is larger compared to different types of building of the same size (Rada,1996)

The hotel industry was ignorant about the damage caused to the environment because of its services and operations. But with the emerging awareness of environmental protection and the developing green consumerism has brought the needed criticism for the existing practices in hotels.
However, to reduce the drastic impact of the industry on environment and to be energy efficient the hotel industry needs to address three main issues regarding the design, management and customer attitude.

Base Study Hotel
Hotel Galexie is a 32 room hotel located in Oxford, UK, and has had extensions added over the years, the hotel is converted from Victorian house, which has had renovations over the time since 60 years, the recent one was done in 2012. A Post Occupancy Evaluation was carried out on the hotel and the following issues were found:
1. Main dining area is in a conservatory, which consumes the most energy for heating and cooling, as the glass structure is 20 years old and hasn’t been upgraded.
2. Only the roof and the flooring have insulations while the walls are 2 brick thick with 10mm plaster board.
3. Windows on the front façade of the ground floor are double glazed while all other windows for other rooms are sash windows.
4. The hotel has LED fixtures but some of the corridors on the first floor still have incandescent lights.

Temperatures measured in improvised rooms, average was 18-25, while the rooms on the 1st and 2nd floor were colder.

Major issues were also understood after interviewing the clients and the managers. While the issues, which customers pointed out were related to comfort, while interviewing the managers it was concluded that the hotel lacks environmental policies and the staff was not aware of basic environmental concerns required in a hotel.

Analysis of Clients Interviews was as follows:
Noise issues in the rooms facing the roadside.
Temperature issues in the rooms with sash windows.
Uncomfortable dining area, regarding the temperatures.
Front façade of the hotel not welcoming, interiors are well done.
Were impressed by the low flush toilets, aerated taps, and overall room design.
When booking rooms in this hotel no one had considered eco friendly ness as an aspect.

Conclusions based on the Post Occupancy Evaluation of the hotel
Changes or improvements in the hotel can be done based on low, medium and high budget Improvements with low or minimum budget include training the staff towards sustainable management, use of recycling bins, broachers promoting energy consciousness, changing the sash windows and halogen lights with medium budget, and changing the structure of the conservatory would be high budget. While refurbishments in hotels should be done systematically, ( eg: if halogen lights are replaced whole hotel should have LEDS rather than just one half) The hotel should keep up with the new technology, and new energy efficient systems.
Environmental Management in hotels

Hotels as a building type have a far more negative environmental impact than other building type of the same size. (Rada, 1996). Environmental impact on the natural resources is drastic, and about 75% of the environmental impacts are on water, energy consumption and air, soil, water pollution due to disposing non-durable goods.(APAT 2002)

Hotels have to consider the environment issues if they are to sustain in the growing tourism industry (Webster, 2000; Kasim, 2007). The issue of environment protection has been started to be addressed in the hospitality industry (Erdogan and Baris, 2007) but in most cases hotel managers are the decision makers about the hotel’s environment policy (Bohdanowicz et al., 2005) thus sometimes neglecting some issues which may have tremendous effect on the nature.

Hotel industry flourishes only in a place, which has the capacity to attract tourists. Thus to maintain the natural resources of the place hotels have to incorporate sustainable strategies both related to management as well as design.(Han et al., 2011). By implementing environmental strategies the hotel gains a competitive edge as a sustainable hotel over non green hotels. (Menash, 2004; Penny, 2007).

Thus the hotel management plays an important role in the sustainability aspect of the hotel as the daily functioning is solely depended on the employees and the manager, hence training them and making them aware of these issues helps in reducing the energy consumptions in a hotel as well makes the customers energy conscious.

Customer Attitude in hotels

In order to find out the customers attitude towards sustainability, 32 travellers were interviewed in Oxford, which addressed to the following key research questions:
01: What are the major factors a customer considers while booking a hotel room? Facilities, Location, Budget, Eco friendly services
02: Does the customer pay extra for a green hotel? If yes which green services would have an impact on him to pay more?
03: Does the intention to pay extra for green facilities vary across different demographics? Gender, Age, income
04: Does the traveller consider eco friendly travelling activities?

The interview questions were asked with an intention to analyze the attitudes of the travellers, and their willingness to pay extra for the green services. The main factors 98% tourists considered were budget, location and facilities provided by the hotel while eco friendly services were last on the option of the interviewees.

While only 24% of tourists were convinced to pay extra for green services, and this issue of paying extra for green services related to the study of Manaktola & Jauhari 2007, where customers were willing to stay in green hotels but didn’t want to pay extra for the green services, thus ended up staying in the conventional hotels.

Travellers considered sustainability to be a part of the overall hotel and hence didn’t wish to pay extra for the same(Robinot and Giannelloni 2010).

The answers from the interview also related to (Manaktola and Jauhari 2007, 368) which
stated that customers are unwilling to accept lower quality and would prefer to stay in a hotel which gives more services and comfort for the same price even though it might not be green. “When I travel I expect the hotel to be luxurious more than my house as I am on a break and won’t like to stay in some place which says green and is of low quality” was a response from a frequent traveller. Customers’ demographics also play an important role in hotel selections (Han et al., 2011). In the self-administered questionnaire segregation was made based on gender, age and income. Recycling bins, energy-efficient lighting, recycled paper for promotional materials, changing sheets only when requested, and turning off lights in unoccupied guest rooms are major attributes which guests consider if they want to book a green hotel (Watkins, 1994). Further, despite the fact that travelers in his study said they were likely to stay in hotels that provided such attributes, they were not willing to pay extra for these services.

Conclusion

Hotels have to keep up with the new technology and energy saving equipment’s, and training for the staff to save energy is necessary. Low or minimum budget changes, which do not require major investment, should be taken up, for which the customers should not be expected to pay for. Hence in a long term the hotel can set in medium and high budget changes and become completely green. Green strategies which the hotel has invested on can become the hotels marketing strategy, thus having a competitive edge over the non green hotels. Becoming green in all respects is a process which takes time and effort by the architect, management and the investors. But with steady investment with regards to management, design and customer awareness hotels can become sustainable and energy efficient.

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Time-dependent CFD Simulations Modelling the Effects of Thermal Mass on Buoyancy Driven Natural Ventilation

Junji Zhu

MSc Low Carbon Building Design and Modelling, Loughborough University, UK;

Abstract
With the growing consideration of building energy consumption and indoor thermal comfort, coupling thermal mass with buoyancy driven ventilation has become a popular technique for sustainable building design. It is important for the designer to understand the complex airflow characteristics of natural ventilation coupled with thermal mass effects. Transient Computational Fluid Dynamics (CFD) is a potential tool for simulating and analysing these effects. The aim of this study was to assess the CFD methods for modelling these using a commercial CFD code. A simple box geometry and a typical naturally ventilated classroom model were used as benchmarks in this study. The results illustrate that transient CFD simulations can effectively predict the thermal mass effects on buoyancy-driven ventilation and indoor thermal comfort.

Keywords: CFD, Thermal mass, Natural ventilation

1 Introduction
Buildings consume a lot of energy to keep occupants healthy and comfortable within the built environment. Natural ventilation is a sustainable solution to reduce building energy consumption. Buoyancy driven displacement ventilation is a popular approach for natural ventilation design and the successful design of the Lanchester Library in Coventry University proved the feasibility of natural ventilation in deep plan buildings (Cook and Lomas, 1997). Coupling thermal mass with natural ventilation design is an important passive method to achieve indoor thermal comfort (Shaviv, 2001). The performance of heat storage of thermal mass can be very effective if the diurnal variation of ambient temperature and/or solar intensity is significant (Yam et al, 2002).

Computational Fluid Dynamics (CFD) simulations are widely used to predict natural ventilation based on solving numerical equations of fluid motion (Chen, 2009). However, Linden (1999) pointed out that there was little work on the thermal mass effect on natural ventilation. The thermal mass effects on ventilation is a dynamic process due to the variation of temperature and the heat transfer process through the building envelope and can be a complex scenario. This paper addresses the time-dependent CFD simulation method for evaluating the thermal mass effect on the natural ventilation and indoor thermal comfort.

2 Methodology
2.1 The CFD Model
The aim of the research reported here was to carry out a time-dependent CFD simulation to capture the transient behaviour of the effect of thermal mass on natural ventilation using a well-established commercial CFD code. PHOENICS was used for the current study as it had
been widely used and proved to be a valid simulation tool (CHAM, 2011). A series of simulation cases were carried out based on two benchmark models to check the capability of the transient CFD simulation method for capturing transient behaviours and investigating thermal mass effects.

Benchmark 1 is the simple ‘empty box’ geometry used in the study of Cook (1998). Benchmark 2 is a typical classroom in UK, which refers to the study of Cook et al. (2011). Detailed information of the model dimensions can be found in the respective literature. It is important to point out that Benchmark 2 is simplified compared with the original model as the specific person effect on ventilation is not the focus of this study. Mesh sensitivity studies were carried out for both benchmark cases. The results suggested about 64,000 cells for Benchmark 1 and 147,000 cells for Benchmark 2. Figure 1 shows the final mesh settings used for the benchmark models.

![Figure 1. Final mesh settings of the benchmark models (Left: Benchmark 1; Right: Benchmark 2)](image)

The RNG $k – \varepsilon$ turbulence model was used in this study as it had been proved accurate for these types of flows previously (e.g. Cook and Lomas 1997, Cook 1998, Durrani et al, 2013). Convergence was considered achieved when the total energy residual is less than 1% of the heat entering the domain; and the residual of all the properties is less than $10^{-4}$. With the consideration of both computational time and convergence strategy, time steps of 15 minutes and 5 minutes were used for Benchmark 1 and 2 respectively. The boundary condition of thermal mass was represented using concrete materials. A non-equilibrium wall function was used to model heat transfer between the thermal mass and the surrounding ambient fluid. Buoyancy effects were modelled using the Boussinesq approximation and a loss coefficient of 2.69 (equivalent to a discharge coefficient of 0.61) was specified at each opening. A point heat source with a source strength of 200W was used in Benchmark 1 and a heat emission per person of 90W was used in Benchmark 2. The Immersol radiation model (CHAM, 2011) was used for Benchmark 1 to model radiative heat transfer between thermal mass and indoor air. However it was observed in Benchmark 2 that converge could not be achieved with both the radiation model and the turbulence model used due to the complexity of the model and the difference in the order of solving the equations. A simplified method was therefore used to represent the radiative heat by a plate of heat flux at the ceiling level. This method proved accurate with respect to both air change rate and average room temperature compared with the study of Cook et al. (2011).

### 2.2 Design of simulation cases
The current study firstly used the simple ‘empty box’ Benchmark 1 model to verify the accuracy of the transient simulation on ventilation prediction and the ability of the simulation to capture transient behaviour. Secondly, the thermal mass effect on buoyancy driven ventilation and indoor thermal comfort was analysed for Benchmark 1. Then the simulation methodology can be applied on the practical building Benchmark 2 model to evaluate the thermal mass effect. To achieve the time-dependent simulation with varying boundary conditions, an initial simulation was run for each simulation case to get the conditions at the end of the interested time period; then the results were used as initial conditions for subsequent simulations with the modified boundary conditions.

Simulation methodology for the Benchmark 1 model can be summarised as follows:
- Check the accuracy of the transient CFD model based on Durrani et al. (2013)
- Investigate thermal mass effect with different thermal mass materials
- Investigate thermal mass effect with a variable ambient temperature

The simulation cases for Benchmark 2 model are conducted as follows:
- Transient simulation of ambient temperature of 25.4 °C to get the initial conditions
- Use the previous results to continue simulation with ambient temperature of 28 °C
- Repeat the simulation with and without thermal mass settings

3 Results and discussion

3.1 Reliability of transient CFD simulation method
According to the study of Durrani et al. (2013), the time to reach an equilibrium state for natural ventilation flow was investigated based on Benchmark 1. Convergence criteria are achieved for each time step of the transient simulation and the steady state simulation. The relation between dimensionless time to convergence and dimensionless room temperature is plotted in Figure 2. Full numerical expressions of dimensionless parameters were discussed in the study of Durrani et al. (2013).

![Figure 2. Relation between dimensionless time to convergence and dimensionless room temperature](image)

The results agree with the study of Durrani et al. (2013) that the dimensionless room temperature reaches the equilibrium state ($\theta \approx 1$) after 3.5 times the timescale for convergence.
to equilibrium ($\tau \approx 3.5$). This agreement demonstrates the reliability and accuracy of the transient CFD model. The time-dependent simulation technique can be used in further simulation cases of the thermal mass effect.

### 3.2 Thermal mass simulation

Four simulation cases were considered including the original Benchmark 1 model without thermal mass, the Benchmark 1 model with 0.1m width heavy weight thermal mass on both side walls, the Benchmark 1 model with 0.1m width light weight thermal mass on both side walls and the Benchmark 1 model with 0.05m width heavy weight thermal mass on both side walls. It was assumed that the thermal mass materials had been cooled to 15 °C after night cooling, so an initial temperature of 15 °C was set at the surface of each thermal mass material. Transient simulations were carried out for 20000s with time steps of 100s; convergence criteria were achieved for all the time steps of each simulation case. The simulation results of average air temperature are shown in Figure 3, only the results of the first 20 steps are plotted because there is no significant change of the properties after a 20 time steps period.

![Figure 3 Simulation results of average air temperature with different thermal mass conditions](image)

Figure 3 shows that different thermal mass effect on the average air temperature can be simulated with the transient CFD simulation method. Thermal mass with lower initial temperature has a cooling effect and the more total heat capacity thermal mass material posses, the lower the average air temperature in space. The results also prove the feasibility of the simulation method.

### 3.3 Thermal mass under various ambient temperatures

In the real case scenario, the ambient temperature changes over time, which can influence the performance of buoyancy driven natural ventilation. As a result, this study considered transient simulations with various ambient temperatures. Only the no thermal mass condition and 0.1m thickness side wall thermal mass are considered based on the Benchmark 1 model. The ambient temperature changes hourly with the following order: 18 °C, 20 °C, 24 °C, 18 °C and 28 °C. Convergence is achieved by the end of every time step period. With the consideration of thermal response speed of the two simulation cases, Table 1 summarizes the
changes of average temperature at the end of each hourly period responding to the changes of ambient temperature.

Table 1. Changes of average temperature at equilibrium state after changing the ambient temperature

<table>
<thead>
<tr>
<th>Changes of ambient temperature/ °C</th>
<th>Changes of average temperature (no mass)/ °C</th>
<th>Changes of average temperature (heavy)/ °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 to 20</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>20 to 24</td>
<td>4</td>
<td>3.4</td>
</tr>
<tr>
<td>24 to 18</td>
<td>-6</td>
<td>-5.1</td>
</tr>
<tr>
<td>18 to 28</td>
<td>10</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Table 1 illustrates that the model with thermal mass has a lower temperature changes than the no thermal mass model. This confirms that the building constructed with heavy weight thermal mass has less temperature variations responding to the various external air temperatures. The results also suggest thermal mass is an efficient design technique to maintain a relatively more stable indoor environment and improve the indoor thermal comfort.

3.4 Thermal mass simulation for practical building

With the simplified method to present radiative heat, this study modelled the different thermal mass performance based on the Benchmark 2 model. Ambient temperature changed from 25.4 °C to 28 °C according to the weather data. In constant to the setting of Benchmark 1, the thermal mass had no initial temperature. Results illustrate that thermal mass can be modelled for practical building using the simulation method described here.

![Figure 4 Fresh air supply rate for three simulation cases](image_url)

With the consideration of indoor air quality, Figure 4 plots the results of fresh air supply for the three simulation cases. It appears that thermal mass has little effect on ventilation flow rate. About 15 l/s of fresh air can be provided to each occupant. The sudden increase in ambient temperature leads to a reduction of the air flow rate, but the lowest value is about 13 l/s per person fresh air, which also complies with the indoor fresh air requirement of 10 l/s per person (CIBSE, 2006). However, this result suggests a potential problem. If the natural ventilation system is designed with criteria of 10 l/s per person of fresh air, under the sudden heat wave conditions, it is possible to have a 5 to 10 minutes period during which insufficient fresh air is supplied by the natural ventilation system. To avoid the problem, it is recommended that a transient simulation method be used to analyse the natural ventilation performance.
Conclusions
This study investigated the use of time-dependent CFD techniques to effectively simulate the thermal mass effect on buoyancy driven natural ventilation. The simulation technique proved reliable and a series of simulation cases based on the two benchmark models illustrated that thermal mass can provide a more comfortable indoor environment when the ambient temperature is high. Thermal mass also appears to have a slower thermal response speed. Simulation results of ventilation performance during sudden heat wave showed a period of 5 to 10 minutes when there was insufficient fresh air. Designers are advised to consider this phenomenon in order to achieve satisfactory indoor air quality. Comparison of the simulation results with different thermal mass materials illustrated that CFD simulations modelled the thermal mass effect reasonably well. However, no experimental data is available for validation. It is recommended that further work be carried out to verify the heat transfer behaviour of the thermal mass.

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References
Computational Fluid Dynamics (CFD) Modelling of a Novel Active Phase Change Material (PCM) Cooling System

Parvaneh Khodadadi Andebil¹, Zahir Dehouche², Efstathios Chrysafis, Gideon Susman

¹ MSc Graduated Student in Sustainable Energy - Technologies and Management, Brunel University, London, UK, p.khodadadi.a@gmail.com
² Lecturer - MSc Course Director (Sustainable Energy Technologies and Management), Department of Engineering and Design, Brunel University, London, UK, zahir.dehouche@brunel.ac.uk

Abstract
In the UK, 40% of energy consumption and carbon emissions come from buildings due to the building development processes and Heating, Ventilation and Air Conditioning (HVAC) systems. These systems are used to keep the building temperature within the required thermal comfort zone. Consequently, developing more efficient heating and cooling systems would have a significant impact on reduction of energy consumption. The main purpose of this paper is the reduction of the amount of energy that has been consumed for cooling systems in the UK office buildings during hot summer days by using Phase Change Materials (PCMs) in novel cooling systems such as Thermal Energy Storage (TES) systems. Differential Scanning Calorimeter (DSC) testing has been used to measure the PCM thermophysical properties and ANSYS/FLUENT software has been employed to use these properties and create a steady state simulation of thermal loading at peak conditions inside the building. Eventually, results obtained from the software simulation and empirical equations will be used to calculate heat transfer coefficient for this system.

Keywords: TES system, PCM, DSC, HVAC, ANSYS/FLUENT.

1. Introduction
Buildings are one of the important leading sectors in the energy consumption in the developed countries. As an example, UK buildings account for around 40% of the total final energy consumption and produce approximately 40% of the total CO₂ emissions. Most of the energy consumption increasing in buildings is due to the building development processes and usage of building services such as Heating, Ventilation and Air Conditioning (HVAC) systems. The building services are used to keep the building temperature within the required thermal comfort zone. Therefore, developing heating and cooling systems to be more efficient, and construction of buildings in such a way that minimise their heat gains and losses would have a significant impact on energy consumption reduction and protection of environment. (Department of Energy & Climate Change, 2012)

Nowadays, Thermal Energy Storage (TES) systems are used in buildings to improve the load factor of electricity generation and heating/cooling production. These systems allow heat and cold to be stored and be used later so, they make the process of
heating/cooling more cost effective than conventional systems such as air conditioning, mechanical ventilation, etc. (M.R. Anisur, 2013) Phase Change Materials (PCMs) are one of the TES systems which are used to store the thermal energy at almost constant temperature. During loading of a PCM storage, the PCM absorbs the heat transferred to the storage and its temperature rises. When the PCM reaches its melting temperature, where it has phase changing, the PCM absorbs large amount of heat without any changing in its temperature. Furthermore, during the storage unloading, the PCM reaches its freezing point and releases its store heat while it solidifies. In consequence, PCMs can be used in buildings and contribute to a better indoor thermal comfort for occupants and lower global energy consumption. (Jaber and Ajib, 2012)

2. System Design
The novel PCM cooling system which is considered for this paper is consisted of an array of six black finned tubes which are filled with pure PCM and suspended from the ceiling of a room. The room represents a working place in an office building in which includes electrical equipments such as computers, printers, lamps, etc. and workers. In order to simulate the solar and internal heat gains from people and equipment, a heater with a rated power of 150 W is placed inside the room. According to the CIBSE building regulations L2A guide for new commercial buildings, the average heat gains should be between 35 and 40 W/m². (Chrysafis, 2012)

Likewise, regarding the CIBSE guide A and B, the maximum air temperature for standard office environments should be 24°C where comfort cooling is applied. (CIBSE, 2006) Thus, a PCM with high latent heat of fusion and high melting/freezing temperature should use for this system that keep internal temperature within thermal comfort zone. CrodaTherm™ 21°C and 25°C are selected because they have several benefits in comparison to other PCMs such as renewable materials sources, high latent heat capacities, long-term stability, lower flammability, etc. Additionally, they would help the system to perform passively through absorbing/releasing heat during day/night. It means the system would have directly contact with thermal space and would not need additional electrical device to operate energy. (Croda Industrial Chemical Company, 2013)

Figure 1. The hanging modelling of the finned tubes by geometry of ANSYS Workbench 14.0

3. Methodology
The aim of this study is reduction of the amount of energy consumption for cooling systems in the UK office buildings during hot summer days by using a novel PCM cooling system. Differential Scanning Calorimeter (DSC) testing is used to measure the PCM thermophysical properties and ANSYS/FLUENT software is employed to use these properties and create a steady state simulation of thermal loading at peak conditions inside the room.
3.1. DSC Analysis
The DSC device is used to measure the amount of energy that is absorbed or released by a PCM sample when it is heated or cooled and provides quantitative and qualitative data on endothermic and exothermic processes such as latent heat of fusion, melting and freezing temperature, etc. First, the PCM sample should be weighted and then placed into a suitable pan and inserted into the DSC for test. The PCM sample is weighted in the following method: (weight of pan + weight of PCM sample) - (weight of pan)

<table>
<thead>
<tr>
<th>Material</th>
<th>Lid (mg)</th>
<th>Pan (mg)</th>
<th>Pan + PCM (mg)</th>
<th>PCM (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CrodaTherm™ 21</td>
<td>47.3</td>
<td>60.1</td>
<td>79</td>
<td>18.90</td>
</tr>
<tr>
<td>CrodaTherm™ 25</td>
<td>47.6</td>
<td>60</td>
<td>72</td>
<td>12</td>
</tr>
</tbody>
</table>

3.2. Simulation
3.2.1. Numerical Simulation
ANSYS/FLUENT software is used to simulate the air flow due to natural convection within the room that is caused by the heating and cooling effect of the heater (heat source) and finned tubes (cool source) respectively. The model simulates a system for middle of a summer day with peak loading: air at 27°C (300K), finned tubes at the peak melting temperature of the CrodaTherm™ 21, 24.19°C (297.19K), maximum heat gain (150W) within the space and heated surfaces of the heater at a constant temperature of 145°C (418K).

3.2.2. Governing Equations
Tsubouchi and Masuda (1970) described a method for evaluating convective heat transfer coefficients of rectangular and annular finned tubes. They performed experiments in air and measured the convective heat transfer coefficients for the circumferential tips and tubes plus fin surfaces separately. (Couch, 2010)

The equations are provided below for evaluating the transfer coefficient of the tubes plus fins in the case of short fins $1 < \zeta < 1.67$:

1. Nusselt Number:
\[ Nu_s = C_0 Ra_0^{\beta} \left(1 - \exp\left[-\left(\frac{C_1}{Ra_0}\right)C_2\right]\right)^{C_3} \]
\[ C_0 = -0.15 + \frac{0.3}{\zeta} + 0.32\zeta^{-16} \]
\[ C_1 = -180 + \frac{480}{\zeta} - 1.4\zeta^8 \]
\[ C_2 = 0.04 + \frac{0.9}{\zeta} \]
\[ C_3 = 1.3(1 - \zeta^{-1}) + 0.0017\zeta^{12} \]
\[ P = 0.25 + C_2 C_3 \]
\[ Ra_0 = Ra_s \zeta \]

2. Rayleigh number: $Ra_s = \frac{\beta^2 (g\beta(T_w-T_0)S^4)}{\mu^2 D}$
\[ \beta = \frac{1}{T_{film}} \]

3. Heat transfer coefficient:
\[ h = \frac{Nu_s k}{S} \]

4. Heat transfer coefficient:
\[ h = \frac{\dot{q}}{A_{finned\ tube}(T_{air}-T_{finned\ tube})} \]
4. Results and Discussion

4.1. DSC Results
The obtained values by using DSC analyses for the CrodaTherm™ 21 and 25 are shown in Table 2. In addition, two thermographs (Figure 2) show curves for freezing and melting phases of CrodaTherm™ 21 from left to right respectively.

Table 2. Properties of CrodaTherm™ 21 and 25

<table>
<thead>
<tr>
<th>Property</th>
<th>CrodaTherm™ 21</th>
<th>CrodaTherm™ 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Melting</td>
<td>24.19°C</td>
<td>26.68°C</td>
</tr>
<tr>
<td>Onset Melting</td>
<td>21.48°C</td>
<td>22.75°C</td>
</tr>
<tr>
<td>End Melting</td>
<td>26.92°C</td>
<td>28.76°C</td>
</tr>
<tr>
<td>Latent Heat (melting)</td>
<td>152.686 J/gr</td>
<td>167.08 J/gr</td>
</tr>
<tr>
<td>Peak Freezing</td>
<td>15.94°C</td>
<td>19.76°C</td>
</tr>
<tr>
<td>Onset Freezing</td>
<td>19.41°C</td>
<td>21.80°C</td>
</tr>
<tr>
<td>End Freezing</td>
<td>13.41°C</td>
<td>17.40°C</td>
</tr>
<tr>
<td>Latent Heat (freezing)</td>
<td>-155.286 J/gr</td>
<td>-165.200 J/gr</td>
</tr>
</tbody>
</table>

Figure 2. The DSC thermograph of the freezing (left) and melting (right) curves for CrodaTherm™ 21

4.2. Experimental Results With and Without the Novel PCM Cooling System
Two experimental tests are performed inside the room: (Chrysafis, 2012)

(1) In the case without the PCM system, air temperature in the centre of the room increases from 20°C to 23°C in only 8 minutes. At that time the air conditioning was put into operation in order to reduce the temperature to approximately 22°C. When the temperature drops, it stops working and whenever the temperature rises above 23°C, its operation commences again. In this condition the power consumption varies from around 800 – 1050 W and when the temperature dropped to 22°C and the compressor stopped working; the average power consumption is 311.11 W.

(2) For the case with the PCM system, again with a starting point of 20°C, the temperature reaches 23°C only after 122 minutes that occurred in 8 minutes for the case without the PCM system. At that time the air conditioning was engaged, but up to minute 149 the compressor did not have to function in order to maintain the temperature at 22°C. But even when it works, the power consumption is significantly less than the case without the PCM system. Specifically, it is about 866 – 877 W and when the temperature dropped to 22°C; the average power consumption is substantially lower with a value of 78.3 W.

The graphs of the internal and external air temperatures and power for both cases are displayed in Figure 3.
What affected the case with the PCM system is the fact that the PCM absorbs a substantial amount of the produced heat by the heater and in that way assisted the air conditioner, allowing it to work less. Furthermore, the fact that it delays the increase of the room air temperature, led to a lower average of 22.26°C.

4.3. CFD Results with the Novel PCM Cooling System

Figure 4 shows the natural convection simulated inside the room that is created by the heating and cooling effect of the heater and finned tubes respectively. Stratification of air temperatures is apparent inside the room which is due to pressure and density variations. Warmer air leaves the heater and goes up because of reduction of pressure and density. It plumbs across the ceiling where it meets the finned tubes. Finned tubes cool the surrounding air by absorbing heat, then the cooled air sinks below finned tubes and mixes with the warmer surrounding air.

4.3. Heat Transfer Coefficient Results

By using of equations in section 3.2, an estimation is made for the heat transfer coefficient of the short finned tube. Then, it is compared with the obtained results from experimental tests and FLUENT simulation in Table 3.

<table>
<thead>
<tr>
<th>Method</th>
<th>Heat Transfer Coefficient W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>4.29</td>
</tr>
<tr>
<td>Analytical</td>
<td>3.50</td>
</tr>
<tr>
<td>CFD</td>
<td>4.78</td>
</tr>
<tr>
<td>Error</td>
<td>36%</td>
</tr>
</tbody>
</table>

Figure 5. Experimental heat transfer coefficient, heat flux and air-tube temperature difference over time for the case with the PCM system. (Chrysafis, 2012)
According to the results, CFD model of the system reveals a moderately higher heat transfer coefficient in comparison with analytical and experimental results. The difference between these values is mainly due to the operation of air conditioner in experimental tests.

5. Conclusion
The objective of this paper was to study and simulate of a novel PCM cooling system based on Bio-PCMs to reduce energy consumption and consequently CO₂ emissions in the UK office buildings. According to the results obtained by CFD simulation and the DSC device, the selected PCMs have capability to absorb large amount of heat while melting without increasing of temperature. Hence, it showcases the benefits of PCMs integration in a building cooling system. Furthermore, the experimental results show that the novel PCM cooling system can save about 50% of energy consumption and carbon dioxide that produced daily inside the room. Eventually, this system has a potential to yield up to 34% savings of energy consumption and CO₂ emissions annually. However, to produce more accurate results and have a wider view, the energy and carbon emissions that are embodied in the manufacturing of the system should also be taken into account. Ideally, its transport and disposal would also have to be considered, however this is a very complicated matter, outside the time boundaries of this paper.

<table>
<thead>
<tr>
<th>Without the PCM System</th>
<th>With the PCM System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Energy Consumption</td>
<td>1045.98 Wh/m²</td>
</tr>
<tr>
<td>Daily CO₂ Emissions</td>
<td>540.75 gr/m²</td>
</tr>
</tbody>
</table>

References


Daylighting and LENI calculations

Carlos Val¹ and Luisa Brotas²

¹ MSc Architecture, Energy and Sustainability, Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University, cd.val@live.com
² Low Energy Architecture Research Unit, Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University, Central House, 59-63 Whitechapel High Street, London E1 7PF, UK, l.brotas@londonmet.ac.uk

Abstract
This paper addresses a recent lighting methodology, defined in the European Norm 15193, that adopts the calculation LENI - Light Energy numeric indicator - as a standard/comprehensive calculation method and in its implementation (simplified method) in the latest British Building Regulations Part L: Conservation of fuel and power, which came into force on April 2014. A sensitivity study is presented for a typical open plan office, for three different opening sizes and three different artificial lighting solutions. Moreover the model is assessed for 7 different locations across Europe. Results obtained from these calculations, are checked against advanced daylight simulation software which takes into consideration the potential of sunlight availability for energy savings with climate based daylight metrics based on real sky conditions available at the building site throughout the year.

Keywords: Daylighting, Energy Efficiency, LENI.

1 Introduction
Lighting accounts for around 5% of the total primary energy consumed including transport and industry in EU. (Baker, 2002) However, in buildings of the office type this figure is much higher. A study done in the UK for four different types of offices: naturally ventilated, cellular and open-office and air conditioned standard and prestige, identified that lighting accounts for 14 to 27% of the typical CO₂ emissions (between 17 and 45% of the annual delivered electricity). (DETR 2003) In such buildings the exploitation of daylight can be a good solution to reduce the energy use, as a large percentage is mostly occupied during daytime.

Likewise the Royal Institute of British Architects (RIBA) study of case buildings classified as energy efficient concluded that in general the shallow plan, daylit and naturally ventilated had around half of the primary energy consumption of the deep plan, air-conditioned using extensive artificial lighting. (Kasabov, 1997) A BRE study showed potential energy savings up to 40% in offices and factories through the installation of suitable daylighting controls to ensure the displacement of energy when electric lighting is not needed. (Littlefair, 2006) Another recent detailed study made with the SBEM (simplified method for building regulation Part L in non-domestic buildings) and DSM (Dynamic Simulation Method) of 21 different office scenarios concurred the importance of shallow plans to achieve CO₂ reductions due to daylight harvesting and the possible use of natural ventilation. Light controls for daylight as well as the requirement of higher luminance efficacy for luminaires
(75 lm/w) is suggested as effective strategies to achieve Zero Carbon in non-domestic buildings (DCLG, 2011)

Work to be presented next highlights the importance of quantifying the reduction of the energy use for lighting. BS EN 15193 (2007) provides a calculation method to estimate the electrical energy saved when using daylighting in conjunction with electric lighting, i.e. using controls. Therefore this paper aims to:

1. Test the accuracy of the current estimation methods for energy lighting performance, i.e. Quick Method and Comprehensive Method found in EN15193 and the one found in the Non Domestic Building Services Guide. (HMG, 2014a)
2. Compare the results against more advanced estimation methods, which consider the full potential of the sunlight available at the location.
3. Assess the applicability of each method.

2 Case studies – lighting solutions
Figure 1 presents 3 lighting solutions for an office space and its lighting specifications. These are to be compared with different metrics and for different locations across Europe.

The model is a side lit open plan office (with dimensions: 10m wide, 6m depth and 2.4m height). The reflectance of the surfaces is set to 80, 50 and 20% for ceiling, walls and floor, respectively. Three different window to wall ratios of 30% (weak) 40% (medium) and 90% (strong) were analysed. For the purpose of this study the height between the window lintel and the task area (working plane at 0.85m) is kept constant, just varying the width of the openings. As result, the depth index is the same for the 3 variants in study. No obstructions have been considered in this study. Further details on other specifications can be seen on Val (2014).
3 Results and discussion
LENI stands for Lighting Energy Numeric Indicator, which is the energy demand for lighting during a year per square meter expressed in KWh/m²/year. Figure 2 shows the LENI values obtained for London with the methods described in EN15193 and Part L. (HMG, 2014b) Results obtained using the comprehensive method are between 50% and 35% lower than those obtained using Part L parameters, and between 60 to 45% compared to the EN 15193 quick method. This is due to higher dependency factors considered with Part L regulation and the quick method compared to the ones calculated comprehensively.

![LENI results comparison](image1)

Figure 2 LENI results comparison

Taking into account that the energy limit stated in Part L2A (buildings other than dwellings) for this model is 20.82 KWh/m²/y. (HMG 2014b) Option 1 does not comply for the ‘Quick’ and ‘Part L’ methods, while results from the ‘Comprehensive’ method widely comply with the energy limit. Options 2 and 3 are within the energy limits for all methods investigated. The differences between these two scenarios are less than 10% for all calculations.

It is worth to note that the selection of the method will not significantly affect compliance as it does the space design. The same design using different calculation methods will yield differences up to 90% in energy use. While the energy limits can still easily be achieved in an office space with simplified methods, they are expected to be more stringent in coming regulations updates. Moreover there is a move towards the adoption of more comprehensive methods. (BSI, 2008; SLL, 2009; EN12464, 2011; EN15251, 2007)

![LENI Results](image2)

Figure 3 LENI calculation results for three different uses of Daylight at different locations across Europe
Figure 3 shows the results of the 63 different calculations performed in the present study. The fair but increasing trend from left to right highlights a positive correlation between higher energy use and higher latitudes in Europe. This is a result of fewer hours of daylight in the working period considered. (Brotas, 2004) The weak line corresponds to the minimum opening size studied, being obviously the more energy dependant. See also Figure 4 for the Daylight supply factor calculated for the different locations.

![Daylight Supply Factor (Fds)](image)

Figure 4 Daylight supply factors

The Daylight supply of a zone benefiting from daylight depends on the geometric boundary conditions described by the transparency index $I_T$, the depth index $I_D$ and the obstruction index $I_O$. This Daylight supply factor concept included in the comprehensive LENI calculation has a strong analogy with the Daylight Autonomy (DA) concept defined by Association Suisse des Electriciens in 1989 and later improved by Christoph Reinhart (Reinhart, 2006). DA represents the percentage of annual daytime hours that a given point in a space is above a specified illumination level.

A comparison between the London DA500 (Daylight autonomy for 500lx) obtained using Ecotect 2011 software and the Fds (Daylight supply) obtained with the LENI method is presented in Figure 5.

![Daylight Autonomy Vs Daylight supply](image)

Figure 5 Daylight Autonomy Vs Daylight Supply

The Fds results overestimate the DA (500lx) ones. Figure 6 shows how the values obtained for with DA and Fds for the 30 and 90% wwr configurations are within an acceptable range of accuracy of 5%. However, the Fds is 10% higher than the DA for the intermediate scenario of 40% wwr.
Besides the geometry of the space and the latitude (solar geometry) of the place, the daylight dependency factors obtained through the comprehensive method also accounts for the local climate influencing the amount of daylight reaching the room. As these calculations were performed with weather files available for the specified locations, other factors such as the sky condition, the cloud cover and pollution at the place can play an important role in the different results presented.

Higher dependency values are a good indication of expected higher electricity demand for lighting. As there is a positive correlation between higher latitudes and daylight dependency factors, it is suggested to adopt larger window areas for northern latitudes. However, the implication the window size to the overall energy performance of the space needs to take into consideration other thermal aspects. Compliance with UK building regulation Part L2A adopting the Simplified Building Energy Model (SBEM) can be seen at Val (2014).

Nevertheless the value of Daylight dependency factor adopted in the UK calculation method described in the Building Services compliance guide (HMG, 2014a) is 0.8. This is relatively high compared to the ones obtained using the comprehensive method, which are between 0.43 and 0.61 in this case study. This should produce lower energy consumption than predicted once the building is functioning.

4 Conclusions
Daylighting has been effectively implemented into Building Regulations Part L with the adoption of the Lighting Energy Numerical Indicator method. This takes into account daylight availability, occupancy, operating hours and light controls to predict energy use for lighting in a building. This is a major move addressing the contribution of daylight to the energy savings in lighting. It is also a change from regulating light in terms of the power of luminaires and lamp luminous efficacy to predict the energy use for lighting and controls.

The accuracy of the different methods has been tested and wide discrepancies were found. The higher differences were found between the Comprehensive method and the Quick method, both described in EN 15193. The method described in Part L lies between these two, although the maximum energy limits permitted in UK regulation are between 35% to 60% lower than the ones recommended in the European Norm. These discrepancies, in theory, will only result in lower energy consumption than predicted.
The comparison of the LENI calculation methods with advanced daylighting simulation tools showed that the comprehensive method is close in accuracy (less than 10%) to results using DA with software. However, time invested in software training also needs to be considered.

The applicability of each method can then be generally defined as follows:

- **Quick Method (including Part L)**
  Easy to apply and understand. Errors are easily detected and corrected. If accuracy of estimation is not paramount, this method would be recommended for junior designers.

- **Comprehensive Method**
  Cumbersome at the first sight, although with not much practice the routine becomes easily understandable and logical. The errors are detected easily, just going back through the values and calculations. The accuracy of this method is quite acceptable.

- **Advanced Daylighting simulation tools**
  These tools may provide the most accurate results once are well known. However, the long software training needed to perform accurate estimations, added to the complexity of the workflow make these specialized tools only used by highly experienced professionals. Add the fact that some software does not inform the user of errors on the calculations nor on data inputted. This is often frustrating when the results are incoherent.

**References**


The feasibility of natural ventilation in plus energy houses in Germany

George Papachristou¹, Malcolm Cook² and Jan Cremers³

1 MRes Energy Demand Studies, Loughborough University, Loughborough, LE11 3TU, UK, g.papachristou-12@student.lboro.ac.uk;
2 School of Civil and Building Engineering, Loughborough University, Loughborough, LE11 3TU, UK
3 Hochschule für Technik (HFT), Stuttgart, Germany

Abstract
The Energy Performance of Buildings Directive of the European Commission has set a zero energy goal for all new buildings by the end of 2020. One of the relatively recent housing concepts is the plus energy house, which produces more energy than it consumes. Plus energy houses are generally ventilated by MVHR systems. However, many researchers have expressed concerns about the performance of such systems in terms of indoor air quality, thermal comfort and total carbon emissions. Thus, this study aims to investigate whether natural ventilation can be an integral feature of plus energy houses in central Europe. This was achieved by testing various CO₂-based demand control ventilation strategies for the climate of Stuttgart. The results showed that the proposed strategy resulted in an annual energy surplus of 1,299 kWh for home+, while maintaining acceptable indoor conditions throughout the day both in terms of indoor air quality and thermal comfort.

Keywords: Natural ventilation; Demand control ventilation; Plus energy houses

1 Introduction

More than one quarter of energy use in developed European countries is attributed to the residential sector (DECC, 2014). In response to that, the European Commission published the Energy Performance of Buildings Directive (EPBD) (Directive 2010/31/EU), which sets a zero energy goal for all new buildings by the end of 2020.

A relatively new concept that has gained popularity in several European countries is the plus energy house, which uses renewable energy sources in order to produce more energy than it consumes. These houses generally use mechanical ventilation systems with heat recovery (MVHR), as they provide better control over ventilation rates and minimise ventilation heat losses. However, many researchers have expressed concerns about the performance of MVHR systems in terms of indoor air quality, thermal comfort and total carbon emissions (Liddament, 2010) in new dwellings with high standards of airtightness, such as plus energy houses.

Recent research has shown that natural ventilation could be a satisfactory alternative to MVHR in airtight dwellings in mild climates (Sassi, 2013). However, a natural ventilation system has to be designed correctly, as potential failure in ventilating new airtight dwellings effectively could result in a range of adverse effects. Evans et al (1998) estimated that design, build and operating costs are in the ratio of 1:5:200. This means that poor standards of ventilation can have a significant negative impact on operating costs.
A determinant factor for the success of a natural ventilation system is the way it is controlled. One of the reasons for excessive energy consumption in buildings is the inability of the occupants to comprehend complicated controls. Automatic control of ventilation with manual override is a popular option in non-domestic buildings, with CO₂-based demand control ventilation (DCV) being suggested by CIBSE (CIBSE, 2009). While these systems are not widespread for residential applications, this is expected to change.

Showing the potential of natural ventilation in new dwellings in European countries is especially timely, as these countries are currently exploring ways to achieve their ambitious “zero-carbon” target for new dwellings. Thus, the aim of this study is to investigate whether natural ventilation can be an integral feature of plus energy houses in Central Europe.

2 Methodology

2.1 Choice of modelling software

The combination of dynamic thermal and air flow modelling has been identified as the most appropriate tool in order to test control strategies (Heisleberg, 2002). The simulation software that was used in this study is Virtual Environment by Integrated Environmental Solutions (IES-VE) (Version 2004.0.1). This commercially available software was chosen because of its comprehensive feature set, its extensive validation history and its regular use within academia and the building services industry.

2.2 Case study

Home+ is a small residential building located in Stuttgart, Germany. It was designed by an interdisciplinary team at the Stuttgart University of Applied Sciences (HFT Stuttgart) as an entry for the first edition of the Solar Decathlon Europe competition (Cremers et al, 2010). Home+ has a total usable floor area of 56 m², a floor to ceiling height of 2.5 m and can accommodate a two person household. It consists of four opaque modules separated by a glazed interspace which aims to provide daylight and ventilation to the interior that is enclosed by three of the modules. The fourth module serves as a loggia outside the main entrance. The entire external surface of the building is covered with photovoltaic elements. Figures 1 and 2 show an exterior view and the floor plan of home+, while figure 3 illustrates the model that was constructed in IES-VE.

The envelope of home+ is highly insulated, while an air infiltration rate of 0.6 ach at 50 Pa was assumed. Thermal mass was added to the ceiling in the form of a 230 mm concrete block (k-value: 230 kJ/m²K), while the rest of the timber construction is lightweight. There is a range of appliances and equipment in the house, resulting in variations of the internal gains. Details about heat gains and properties of the building envelope can be found in Cremers et al
(2010). The heating system was set to operate throughout the day, as the house is occupied on a 24 hour basis. The heating period was set from the 1st of October to the 30th of April. A set-point temperature of 20°C was used. Occupancy for the bedroom was assumed to be 23:00-07:00, in accordance with previous studies (Beizaee et al, 2013).

2.3 Control strategies and performance criteria

Two initial groups of control strategies were formed. Group A, which uses ventilation openings that were sized according to CIBSE suggestions, and Group B, which uses ventilation openings that were sized based on instructions of Approved Document F. According to the CIBSE sizing method (CIBSE, 2005b), the required free area is calculated based on the required airflow for the removal of heat emitted in a space. In contrast, Approved Document F (HM Government, 2010) states that background ventilators should be sized for the heating period, while additional needs for ventilation during summer should be covered by purge ventilation (which was not taken into consideration in this study). As ventilation requirements in winter and summer are different, two seasonal ventilation systems were designed: Cross ventilation through high level openings for winter, and stack ventilation with inlets at low level and an outlet on the top of the stack for summer. Moreover, night cooling through high level openings and the stack outlet is also used during summer, while all windows are shaded by internal blinds. The second method resulted in 30% and 92% smaller openings for summer and winter respectively. The choice of set-points was based on CIBSE Guide B (2005a), which states that a CO2 level of 800 to 1000 ppm indicates that ventilation is adequate within a building. The initial control strategies are summarised in table 1.

Based on the results of the initial simulations, a new control strategy was devised in order to improve the performance of home+. In regard to previous work by Khatami et al (2013), an additional group (group R.1) of control strategies was created in order to determine the optimum balance between the minimum free opening area and the maximum CO2 set-point. The impact of increasing the controller resolution was also investigated by investigating a further group of control strategies (group R.2). Initially, an intermediate increment was added to the best control strategy of group R.1. Subsequently a range of CO2 set-points and opening areas were tested in order to identify the best combination.

<table>
<thead>
<tr>
<th>Group</th>
<th>Opening sizing method</th>
<th>Code</th>
<th>Type</th>
<th>Set-points (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CIBSE</td>
<td>A.1</td>
<td>One step</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A.2</td>
<td>One step</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A.3</td>
<td>Two step</td>
<td>800, 1000</td>
</tr>
<tr>
<td>B</td>
<td>Approved Document F</td>
<td>B.1</td>
<td>One step</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B.2</td>
<td>One step</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B.3</td>
<td>Two step</td>
<td>800, 1000</td>
</tr>
</tbody>
</table>

A set of performance criteria was used to assess the effectiveness of each control strategy in terms of thermal comfort, indoor air quality (IAQ) and energy use. The criteria had to be met in both occupied zones of the house (bedroom: 23:00-07:00; living room: 07:00-23:00). Previous simulations of home+ showed that an annual heating energy consumption lower than 3,173 kWh would maintain the energy plus status of the dwelling for the climate of Stuttgart. Additionally, an average CO2 concentration of 1000 ppm during occupancy was considered adequate for ensuring good IAQ. As for thermal comfort, the adaptive standard
was used as it has gained acceptance within the research community for studies regarding natural ventilation. As the standard does not set strict criteria, this study used the same criteria as Beizaee et al (2013). All criteria are summarised in table 2.

### 3 Results and discussion

Table 3 includes the annual predictions of the simulations in both zones for all initial control strategies. Predictions about energy use refer to home+ as a whole.

Table 3. Annual results for all control strategies. Cells that are coloured red indicate that the control strategy did not meet the specific criterion described in the top of each column.

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Energy</th>
<th>IAQ</th>
<th>Thermal comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating Energy (kWh)</td>
<td>Annual average CO₂ concentration (ppm)</td>
<td>Percentage of hours above category II upper limit</td>
</tr>
<tr>
<td>A.1</td>
<td>3113</td>
<td>744</td>
<td>825</td>
</tr>
<tr>
<td>A.2</td>
<td>2930</td>
<td>377</td>
<td>854</td>
</tr>
<tr>
<td>A.3</td>
<td>2851</td>
<td>753</td>
<td>842</td>
</tr>
<tr>
<td>B.1</td>
<td>2791</td>
<td>795</td>
<td>884</td>
</tr>
<tr>
<td>B.2</td>
<td>2259</td>
<td>940</td>
<td>1024</td>
</tr>
<tr>
<td>B.3</td>
<td>2713</td>
<td>824</td>
<td>900</td>
</tr>
</tbody>
</table>

All one-step strategies succeed in meeting the criterion for heating energy consumption. Group A control strategies were less efficient, as their larger openings resulted in excessive heat loss during heating periods. However, the smaller openings of group B led to worse IAQ in both rooms (7-9% higher CO₂ concentration). B.2 fails to meet the relevant criterion, because of the combined effect of small openings and low CO₂ set-points. As expected, strategies with lower set-points (A.1 and B.1) result in lower CO₂ concentrations, because ventilators open more frequently, letting fresh air into the building. As for thermal comfort, it is apparent that overheating is the biggest risk, since 4 out of 6 strategies result in warm discomfort in the living room. The small windows of group B were proven insufficient, even with the use of night cooling and shading. The bedroom rarely suffered from any thermal discomfort during occupancy. This is explained by the lack of solar heat gains overnight and the operation of night cooling only when external temperature exceeded 12°C.

Both two-step control strategies (A.3 and B.3) failed to meet the warm discomfort criterion in the living room, because the lower set-point maintains the windows half-closed, limiting their cooling potential. However, in winter they are useful because they result in lower energy consumption without significant penalties in IAQ. Therefore, refinement was attempted by adopting two-step control strategies in group R.2.

Figure 4 illustrates the seasonal difference in CO₂ concentration each strategy delivers in both rooms. CO₂ levels are low in summer in both rooms, mainly because of night cooling, while in winter CO₂ concentration is elevated, especially in the bedroom for higher set-points (A.2 and B.2). The fact that the bedroom has no ventilators might be a possible explanation, as the internal air flows that ventilate it have higher CO₂ concentrations than the ambient air.

In figure 5, the operative temperatures which lie within each BSEN15251 (2007) category were plotted in the manner suggested by the standard. Similarly to table 3, it is apparent that overheating in the living room is the main problem for strategies with small openings. Thus, small windows could be used during winter in order to avoid excessive heat loss, while larger openings seem to be necessary for maintaining acceptable temperatures in summer.
Control strategies A.1 (min. hours of overheating) and B.2 (min. energy use) were chosen for ventilating home+ in summer and winter respectively. This combination resulted in a space heating energy consumption of 2,262 kWh, average annual CO₂ concentrations of 868 ppm and 981 ppm in the living room and bedroom respectively and almost no hours of thermal discomfort. B.2 for winter operation was further refined by successively reducing the opening area by 20%, 40% and 50% (Table 4) and by increasing the set-point by 50 ppm.

Table 4. Annual results for R.1 group control strategies. Cells that are coloured red indicate that the control strategy did not meet the specific criterion described in the top of each column.

Table 4 shows that smaller free areas reduced energy consumption, but also deteriorated IAQ in both rooms. A 40% reduction of the base case opening areas reduced energy consumption by 42 kWh. Further refinement was not possible by increasing the set-point, as the bedroom CO₂ concentration failed to meet the IAQ criterion. Different combinations of free areas and set-points resulted in insufficient ventilation either for thermal comfort or IAQ.

Table 5. Annual results for R.2 group control strategies. Cells that are coloured red indicate that the control strategy did not meet the specific criterion described in the top of each column.

Further refinement was achieved by increasing the resolution of the controller in winter. A set-point of 800 ppm was set for the first increment, which was equal to 50% of the total effective area (Table 5). The table shows that this change did not affect the total hours of thermal discomfort. However, it had a significant impact on energy consumption as windows opened more frequently. A lower set-point of 950 ppm and a higher set-point of 1050 ppm achieved the optimum balance between energy consumption and CO₂ concentration. Additionally, a 20% reduction of the area of the first increment further reduced energy demand (2,204 kWh) without compromising IAQ.
4 Conclusions

Natural ventilation can be an integral feature of plus energy houses in central European climates, even with simplified control strategies. Night cooling and shading are considered to be crucial components for the success of natural ventilation in such dwellings. The proposed control strategy resulted in an annual energy surplus of 1,299 kWh for home+ in Stuttgart.

Adopting different control strategies in winter and summer can tackle the seasonal risks of poor ventilation. Correct sizing of the openings is essential as it has a significant effect on energy consumption. The CIBSE sizing method is most suitable for summer ventilation, while Approved Document F guidelines should be followed for background ventilation in winter.

References


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Potential energy and carbon savings of six domestic retrofit options

George Papachristou¹ and Steven Firth²

1 MSc Low Carbon Building Design and Modelling, Loughborough University, LE11 3TU, UK, g.papachristou-12@student.lboro.ac.uk;  
2 School of Civil and Building Engineering, Loughborough University, Loughborough LE11 3TU, UK

Abstract
Since the majority of the dwellings that will exist in 2050 in the UK have already been built, improvements to the energy efficiency of the UK housing stock will have to be obtained primarily by retrofitting existing buildings. This study uses a bottom-up physical model to explore the potential energy and carbon savings that six retrofit options can deliver to the UK domestic sector. These retrofit options include fabric improvements and boiler replacements and aim to reduce the energy demand for space heating. It was found that 97% of all dwellings can benefit from at least one retrofit option, while the combination of all measures has the potential to reduce CO₂ emissions by 30.1%. A breakdown of energy use by built form, age and floor area showed that detached houses should be targeted as they account for 31.5% of the potential CO₂ emission reductions of the entire housing stock.

Keywords: Retrofit; Residential stock; Bottom-up building stock model; CO₂ emissions; Energy efficiency

1 Introduction
The UK government is legally committed via the Climate Change Act to reduce greenhouse gas emissions by at least 80% by 2050 based on 1990 levels. The Act also introduced five year “carbon budgets” to 2050 and an interim target to reduce emissions by at least 34% by 2020 (HM Government, 2008). The Committee of Climate Change has reported that the UK is not currently on track to meet the third and fourth carbon budgets without a significant increase in the pace of emissions reduction (CCC, 2013).

In 2012, the residential sector accounted for 26% of the total CO₂ emissions (DECC, 2013a). As around 75% of the dwellings that will exist in 2050 have already been built (Ravetz, 2008), a strategic overhaul of the existing housing stock is considered essential for meeting the statutory commitments.

In an attempt to improve the uptake of energy efficiency measures in the domestic sector, the UK government introduced the Energy Act 2011. The Green Deal, which is an important component of the Act, is an innovative financing mechanism that allows consumers to employ energy efficiency improvements in their properties at no upfront cost and pay back through their energy bills (DECC, 2010). Alongside the Green Deal, the Energy Company Obligation (ECO) focuses energy companies on improving the ability of the vulnerable and those with lower income, and on installing solid wall and hard-to-treat cavity wall insulation, which ordinarily cannot be financed solely through the Green Deal (DECC, 2010).

The majority of energy consumed in the domestic sector is for space heating (65.6%) with natural gas being the predominant fuel source (79.6%) (DECC, 2013b). The ambitious
reduction targets seem impossible to be met without a fundamental change to the way homes are heated. However, there is a lot of scepticism about the uptake of high cost measures, such as heat pumps, through the Green Deal (Boardman, 2012). As for now, domestic retrofit mainly includes fabric improvement measures and measures that replace the heating system without moving away from natural gas (DECC, 2013c).

As there is undeniable potential in improving energy efficiency of dwellings through installing measures such as condensing boilers and external wall and loft insulation (CLG, 2013), it is clearly important to estimate the impact of Green Deal on reducing carbon emissions from the residential sector by installing common energy efficiency measures. As space heating is the main energy consumer in the residential sector, measures that affect it can contribute significantly to the decarbonisation of the stock. This study aims to explore the energy and carbon savings that different Green Deal eligible retrofit options can deliver to the English housing stock and to identify which dwelling types have the greatest potential for carbon reduction through retrofit.

2 Methodology

The Households, Dwellings and Carbon model (HDC) is a bottom-up energy and carbon model for England, which was developed by Dr Steven Firth of Loughborough University. The model was constructed using spreadsheet software (Microsoft Excel), while the primary source of its input data is the English Housing Survey (EHS) 2008 (CLG, 2008). The 15,505 dwellings of the dataset constitute the “household subsample”, which can be scaled up to represent the 21.2 million occupied English dwellings that were occupied in England in 2008. An average internal temperature of 19°C was assumed for all dwellings. Additionally, average climate data were used so that results would not be skewed by the weather patterns of one particular year. This method was also used in the CDEM model (Firth et al, 2010). The model performs calculations, which are based on BREDEM-8 algorithms (Anderson et al, 2002), directly within worksheets. Figure 1 illustrates the flow of data within the model.

![Figure 1. Flow chart of the Households, Dwellings and Carbon (HDC) model.](image-url)
Empirical validation was carried out by comparing results of the model with measured energy consumption data of the National Energy Efficiency Data-Framework (NEED) (DECC, 2012). Consequently, model results were compared with results of the CDEM model which was based on the EHCS 2001 datasets (Firth et al, 2010). The validation results provided high levels of confidence in using the HDC model, as the estimates it generated were adequately representative of the distribution of energy consumption within the housing stock.

In this study the HDC model was used to generate estimates of energy use and CO₂ emissions for the entire English housing stock for the base case scenario and six different retrofit options (Table 1). These options include Green Deal eligible measures that relate to the space heating energy consumption of dwellings. Recommendations included in the Standard Assessment Procedure (SAP) 2009 document (BRE, 2009) were used in order to define whether a measure should be installed in a property, as the same recommendations are used for producing EPCs during the Green Deal Assessments.

<table>
<thead>
<tr>
<th>Retrofit option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Option 1</strong>: Installation of wall insulation</td>
<td>Insulation is added to all external walls that have a U-value equal or more than 0.6 W/m²K (SAP 2009), while no other measures are installed. This option includes both solid and cavity wall insulation.</td>
</tr>
<tr>
<td><strong>Option 2</strong>: Installation of loft insulation</td>
<td>In dwelling with no loft insulation or with loft insulation thinner than 150 mm, it is topped up to the recommended level of 150 mm (SAP 2009), while no other measures are installed.</td>
</tr>
<tr>
<td><strong>Option 3</strong>: Installation of double glazing</td>
<td>Double glazing is added in all dwellings that have less than 51% of their total opening area already covered with double glazing (SAP 2009). No other measures are installed.</td>
</tr>
<tr>
<td><strong>Option 4</strong>: Installation of wall insulation, loft insulation and double glazing</td>
<td>All measures from options 1, 2 and 3 are installed according to the SAP 2009 recommendation criteria.</td>
</tr>
<tr>
<td><strong>Option 5</strong>: Replacement of old boilers with condensing and condensing combination boilers</td>
<td>Condensing and condensing-combination boilers replace non efficient boilers without changing the fuel (SAP 2009), while no other measures are installed.</td>
</tr>
<tr>
<td><strong>Option 6</strong>: Installation of wall insulation, loft insulation, double glazing and condensing boilers</td>
<td>All measures from options 1, 2, 3 and 5 are installed, when the SAP 2009 recommendation criteria are met.</td>
</tr>
</tbody>
</table>

**3 Results and discussion**

Table 2 shows the number of dwellings in which at least one improvement measure was installed as part of each retrofit option. It also gives information about the average annual gas energy consumption and the average annual total CO₂ emissions of each dwelling type.

It is apparent that the existing housing stock has a great retrofit potential, as 97% of all dwellings need to install at least one of the aforesaid four measures in order to comply with the SAP recommendations, with only purpose built flats having a lower percentage (85%). This can be attributed to three reasons: a) loft insulation has no application in flats, b) flats, along with detached houses, have the largest percentages of recently built dwellings and c) 29% of all purpose built flats (more than in any other category) do not have a boiler, as they use electrical heating systems.

Wall insulation affects average gas energy consumption of the stock the most, as it results in a 29.9% reduction. As expected, the properties that are benefited the most are the ones with either three or four exposed walls. As for condensing boilers, detached houses, semi-detached
houses and end terraces benefit the most with reductions in average gas energy consumption of 16.1%, 15.8%, and 15.7% respectively. This result comes in agreement with NEED, which states that condensing boilers are equally suitable for all these types (DECC, 2012).

Retrofit option 6, which reveals the full potential of all measures, achieves a 46.5% drop in gas energy use and a 30.1% reduction in the total CO2 emissions of the entire housing stock.

Table 2. Breakdown of average gas energy consumption and average annual total CO2 emissions by dwelling type. The number of dwellings in which changes were made is also included for each dwelling type.

<table>
<thead>
<tr>
<th>Number of dwellings (thousands)</th>
<th>End terrace</th>
<th>Mid terrace</th>
<th>Semi-detached</th>
<th>Detached flat: purpose built</th>
<th>Flat: other</th>
<th>All dwellings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case scenario</td>
<td>2,216</td>
<td>4,079</td>
<td>6,274</td>
<td>4,854</td>
<td>3,066</td>
<td>708</td>
</tr>
<tr>
<td>Option 1 (wall insulation)</td>
<td>1,347</td>
<td>3,060</td>
<td>3,593</td>
<td>2,175</td>
<td>1,838</td>
<td>689</td>
</tr>
<tr>
<td>Option 2 (loft insulation)</td>
<td>1,883</td>
<td>3,597</td>
<td>5,380</td>
<td>4,061</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Option 3 (double glazing)</td>
<td>1,042</td>
<td>790</td>
<td>784</td>
<td>655</td>
<td>835</td>
<td>394</td>
</tr>
<tr>
<td>Option 4 (1, 2, 3 combined)</td>
<td>2,060</td>
<td>3,933</td>
<td>5,896</td>
<td>4,355</td>
<td>2,236</td>
<td>698</td>
</tr>
<tr>
<td>Option 5 (condensing boilers)</td>
<td>1,647</td>
<td>2,997</td>
<td>4,775</td>
<td>3,917</td>
<td>1,524</td>
<td>419</td>
</tr>
<tr>
<td>Option 6 (1, 2, 3, 5 combined)</td>
<td>2,174</td>
<td>4,046</td>
<td>6,189</td>
<td>4,777</td>
<td>2,607</td>
<td>707</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average annual gas energy consumption (kWh)</th>
<th>End terrace</th>
<th>Mid terrace</th>
<th>Semi-detached</th>
<th>Detached flat: purpose built</th>
<th>Flat: other</th>
<th>All dwellings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case scenario</td>
<td>17,330</td>
<td>15,395</td>
<td>17,679</td>
<td>20,347</td>
<td>5,452</td>
<td>10,216</td>
</tr>
<tr>
<td>Option 1 (wall insulation)</td>
<td>11,436</td>
<td>10,749</td>
<td>12,107</td>
<td>15,148</td>
<td>3,950</td>
<td>5,630</td>
</tr>
<tr>
<td>Option 2 (loft insulation)</td>
<td>16,596</td>
<td>14,450</td>
<td>16,807</td>
<td>19,267</td>
<td>5,452</td>
<td>10,216</td>
</tr>
<tr>
<td>Option 3 (double glazing)</td>
<td>16,941</td>
<td>14,875</td>
<td>17,337</td>
<td>19,963</td>
<td>5,247</td>
<td>9,481</td>
</tr>
<tr>
<td>Option 4 (1, 2, 3 combined)</td>
<td>18,361</td>
<td>10,941</td>
<td>13,702</td>
<td>15,148</td>
<td>3,784</td>
<td>5,036</td>
</tr>
<tr>
<td>Option 5 (condensing boilers)</td>
<td>14,603</td>
<td>13,020</td>
<td>14,885</td>
<td>17,064</td>
<td>4,711</td>
<td>8,792</td>
</tr>
<tr>
<td>Option 6 (1, 2, 3, 5 combined)</td>
<td>8,776</td>
<td>7,963</td>
<td>9,251</td>
<td>11,515</td>
<td>3,288</td>
<td>4,362</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average annual total CO2 emissions (kgCO2)2</th>
<th>End terrace</th>
<th>Mid terrace</th>
<th>Semi-detached</th>
<th>Detached flat: purpose built</th>
<th>Flat: other</th>
<th>All dwellings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case scenario</td>
<td>5,880</td>
<td>5,312</td>
<td>6,045</td>
<td>8,046</td>
<td>3,358</td>
<td>4,394</td>
</tr>
<tr>
<td>Option 1 (wall insulation)</td>
<td>4,510</td>
<td>4,271</td>
<td>4,759</td>
<td>6,481</td>
<td>2,916</td>
<td>3,190</td>
</tr>
<tr>
<td>Option 2 (loft insulation)</td>
<td>5,710</td>
<td>5,104</td>
<td>5,837</td>
<td>7,733</td>
<td>3,358</td>
<td>4,394</td>
</tr>
<tr>
<td>Option 3 (double glazing)</td>
<td>5,785</td>
<td>5,192</td>
<td>5,957</td>
<td>7,907</td>
<td>3,293</td>
<td>4,208</td>
</tr>
<tr>
<td>Option 4 (1, 2, 3 combined)</td>
<td>4,256</td>
<td>3,964</td>
<td>4,473</td>
<td>6,033</td>
<td>2,862</td>
<td>3,040</td>
</tr>
<tr>
<td>Option 5 (condensing boilers)</td>
<td>5,340</td>
<td>4,842</td>
<td>5,492</td>
<td>7,396</td>
<td>3,211</td>
<td>4,112</td>
</tr>
<tr>
<td>Option 6 (1, 2, 3, 5 combined)</td>
<td>3,942</td>
<td>3,683</td>
<td>4,139</td>
<td>5,600</td>
<td>2,764</td>
<td>2,907</td>
</tr>
</tbody>
</table>

1 For the base case scenario, the number of dwellings refers to the total number of dwelling of the English housing stock. For each retrofit option it refers to the number of dwellings that are affected by this option.

2 CO2 emissions results pertain to all four fuels.

Figure 2 illustrates the relationship between the age of a dwelling and the reduction in its average gas energy consumption for all single-measure retrofit options. For each age band, dwellings were placed in descending order of average annual gas energy reduction.

The graph shows that the oldest a dwelling is, the highest its potential gas energy reduction is likely to be. The potential is lower for newer dwellings, as they were built with higher insulation standards. Wall insulation (option 1) can reduce gas energy demand by more than 30,000 kWh in a large number of large dwellings. Loft insulation (option 2) can also deliver reductions above 20,000 kWh in some cases, while condensing boilers may affect a larger number of dwellings but to a limited extent. Double glazing has a relatively small impact.
Figure 2. Reduction of average annual gas energy consumption for all dwellings of the “household subsample” in respect to each dwelling’s age for retrofit options 1, 2, 3 and 5. The numbers on the upper x axis represent the number of dwellings that were built in each age band.

Figure 3 illustrates the contribution of each dwelling type in the total annual CO\(_2\) reduction according to its age after applying retrofit option 6 across the whole housing stock.

Out of the total CO\(_2\) emission reductions option 6 can achieve, 63.3% are associated with detached and semi-detached houses. Namely, retrofitting semi-detached houses that are built between 1919 and 1964 can decrease the total CO\(_2\) emissions by 18.6%. This is explained by the large number (3,621 thousand) of semi-detached houses that were built during that period. Detached houses might be less, but are generally larger and more exposed. Thus, even newly built ones contribute significantly to the total emission reduction. As for fuels, while gas is the predominant fuel used for space and water heating, oil fired heating systems in pre-1850 detached houses offer a good opportunity for retrofit.

**4 Conclusions**

There is huge ground for retrofit in the existing housing stock, as 20,500 thousand dwellings need to install at least one retrofit in order to comply with the SAP 2009 recommendations. This fact is indicative of the low efficiency of the English housing stock.
Option 6 is capable of meeting all carbon budgets, as it can achieve a 30.1% reduction in CO₂ emissions, considering that the 23% reduction target of the first budget has already been met.

Wall insulation is the measure with the largest impact on energy consumption and CO₂ emissions. Thus, its inclusion in any retrofit strategy that aims to improve the energy efficiency of the stock is crucial.

The large number of semi-detached houses built between 1919 and 1964 makes them the highest potential contributor in CO₂ emission reductions. However, detached houses may be 22.6% less, but they can have an equally high contribution (31.5% contrary to 31.8% of semi-detached houses). As for fuels, priority has to be given to oil fired systems that are common in old detached houses and gas fired systems that are widespread across the entire stock.

References


Are ventilation cooling towers an important element of plus-energy houses in southern Europe?

Francesco Babich¹, Malcolm J Cook¹ and Jan Cremers²

1 Loughborough University, School of Civil and Building Engineering, LE11 3TU Loughborough, UK
2 Hochschule für Technik Stuttgart, 70174 Stuttgart, Germany

Abstract
Cooling homes is important in order to maintain acceptable internal comfort, especially in southern European climatic zones. This research project examined one main hypothesis: that cooling towers are an important element of plus-energy houses in southern Europe. In particular, refinements to the design of the existing ventilation tower of a Solar Decathlon House developed by the Hochschule für Technik - Stuttgart are proposed and tested using dynamic thermal and computational fluid dynamics simulations in order to predict energy consumption, mean and peak CO₂ levels, temperatures, ventilation rates, cooling potential, fresh air distribution and indoor air quality. Having analysed wet bulb temperature and wet bulb temperature depression values, eight locations were selected in Greece, Italy, Portugal and Spain to investigate the likely performance of the tower integrated within the building. Results show that the annual energy demand for space cooling can be halved without jeopardising the internal comfort.

Keywords: passive cooling, plus-energy homes, PDEC, CFD, ventilation tower

1 Introduction
Several recent studies have investigated the reduction in energy demand for space conditioning within the residential sector, which accounts for more than the 25% of the entire energy consumption in the EU (Eurostat, 2013). Although energy demand for house space conditioning depends on many factors, in southern European zones, space cooling loads usually have a significant role due to a warmer and drier climate. Moreover, the situation is evolving due to climate change. For instance, colder countries, such as the UK, could experience a warming process over the next few decades (West and Gawith, 2005) and summer overheating in homes is already a problem.

The aim of the research reported here was to identify and test refinements to the design of the existing ventilation tower of a plus-energy house, called “Home+”. In particular, one main research hypothesis has been examined: that cooling towers are an important element of plus-energy houses in southern Europe.

2 Previous work
The “Home+” (fig. 1) is a plus-energy home designed by a multidisciplinary team at the Hochscule für Technik (HFT) Stuttgart in Germany for the Solar Decathlon Europe (SDE) competition and it won the 3rd prize in 2010 in Madrid (SDE, 2010). This building integrates both innovative and traditional technologies, but its
ventilation cooling tower did not perform as expected (Team HFT Stuttgart, 2010). In general, within the literature, little is known about the use of this system in extremely low energy residential buildings.

“Passive house” is a common term for referring to low energy residential buildings and it assumes a well-defined meaning when the German “Passivhaus” standard is considered (Feist et al., 2001). Zero Energy Buildings (ZEB) are the next step. By definition, their annual energy balance is zero due to the implementation of a range of micro-generation technologies (Sartori et al., 2012).

A plus-energy house goes even further, being a residential building whose annual energy balance is positive (Disch, 2009). The reduction of the space conditioning loads with passive solutions is essential in order to reach this target. Evaporative cooling is a low cost solution and it can be efficient in light weight constructions, such as timber houses which are becoming more common in warmer countries.

Pioneering works on downdraught cooling and ventilation towers aimed to improve the ancient wind towers (Bahadori, 1985) and the great potential of this technique in hot-dry climates was highlighted. Different systems have then been tested. Wetted columns performed better with strong wind conditions, while wetted surfaces, such as pads, were preferable with low wind conditions (Bahadori, 1994). The use of wetted curtains suspended inside the column implies smaller droplets, wider evaporation surface and therefore a larger reduction of the air temperature through the tower of up to 15°C (Saffari, 2009; Hughes, 2012).

Several other configurations were tested and in all theoretical studies the value of computer simulations was highlighted, using both dynamic thermal modelling (DTM) (Robinson et al., 2004) and computational fluid dynamics (CFD) (Cook et al., 2000).

Whatever the mechanism used for inserting the water within the air stream is, the evaporation process follows the same thermodynamic principles: air absorbs moisture, therefore it becomes cooler and its wet-bulb temperature (WBT) remains constant (Lomas, 2004). The cooling potential of the system is directly proportional to the wet bulb depression (WBD), while its applicability depends on the WBT (Givoni, 1992). According to internal comfort limits in developed countries, the WBT should be no higher than 22°C (Givoni, 1992).

3. Methodology

In this study, temperature between 20°C and 27°C and absolute humidity between 4 g/kg and 15 g/kg have been assumed as limits for the internal comfort conditions for the analysis of the locations (Givoni, 1992). Climate Consultant, a free computer program developed at UCLA (Climate Consultant, 2014), has been used to select
appropriate locations. Several parameters, such as WBT and WBD have been analysed. Moreover, the number of hours in which direct evaporative cooling can work has been estimated. The weather data used are in EPW format and, when available, the source is IWEC (Weather Data Sources, 2014).

Based on preliminary analyses, 8 European locations were chosen: Cordoba, Sevilla and Zaragoza in Spain; Thessaloniki and Athens in Greece; Evora in Portugal; Catania (Sigonella) and Foggia in Italy.

The main enhancement is the change from a wind-driven system to a buoyancy-driven one, which relies essentially on temperature and moisture content. Different building configurations have been tested, focusing especially on the outlet openings. Both DTM and CFD have been used in order to estimate whether the new designed solutions can work or not and their likely performance in terms of energy savings and thermal comfort.

3.3 Dynamic thermal modelling

DTM has been used to estimate mean and peak CO₂ and moisture content levels, energy consumption and likely water consumption of the system. For this project, IES-VE has been adopted as the main DTM tool.

Firstly, a base-case model of the house has been built using the detailed information described within the German simulation report (Team HFT Stuttgart, 2010) and it has been validated with results from the German TRNSYS model. The main element of comparison was the annual space cooling demand in Madrid.

PDEC system has been modelled in IES-VE using the simplified “post-processing method” (Robinson, 2004), since this is suitable for testing the applicability of the system in many locations. The temperature $T_{\text{air}}$ of the air entering into the living space through the tower has been estimated with the mathematical relation $T_{\text{air}} = DBT - \alpha(DBT - WBT)$, in which $\alpha$ has been assumed equal to 80%, since this is the typical effectiveness of evaporative coolers (Salmerón, 2012). A maximum value for the ventilation rates has been set to 900 m³/h (Team HFT Stuttgart, 2010) and a suitable control strategy has been chosen, based on DBT, WBT, $\alpha$ and the ambient temperature ($T_o$) and moisture content ($g$) inside the conditioned space. In particular, the system operates only when:

$$(DBT > 26°C) \text{ and } (T_o > DBT - \alpha(DBT-WBT)) \text{ and } (g \leq 15g/kg)$$

For each location two simulations have been conducted with the same set-point temperature, 26°C, but one with the PDEC system and one without it. The difference in terms of kWh required for space cooling represents the contribution of the tower.

3.4 CFD modelling

The “post-processing” method requires that the hypothesised ventilation rates are actually realised in practice (Robinson, 2004). CFD analysis was used in this project mainly for this reason, but also to predict fresh air distribution, IAQ and cooling potential. For this project, the Phoenics CFD software (Wu, 2010) was used.

Turbulence was modelled using the two equation CHEN-KIM turbulence model (Wu, 2010), and buoyancy was modelled using the Boussinesq approximation. External pressure has been set to ambient pressure and a 2.69 loss coefficient has been chosen for the calculation of the pressure loss across openings (equivalent to a discharge coefficient of 0.61). The global convergence criterion has been set equal to 0.01%.
A mesh sensitivity analysis has been completed and CFD simulations were run for one specific point in time, 2nd June at 17:30. This was chosen because at this instant, the tower supplies the entire required energy for space cooling. Athens was chosen for the CFD simulation mainly because it is the largest city in the study. Inlets at the top of the tower were assumed to be open continuously and four outlet configurations were tested.

4. Results and discussion

4.1 Energy savings and water consumption

DTM results show that the implementation of the tower within the “Home+” can halve the energy demand for space cooling (tab. 1). The demand peaks are in Sevilla (tab. 1), both with and without the tower, followed by Cordoba, where the maximum effect in absolute terms occurs. Monthly values have nearly the same pattern in all locations: the peak is reached in July and the tower does not affect this profile. Moreover, a noticeable amount of energy from other sources is required in July and August, especially in the warmest locations. In terms of the main research hypothesis, energy results are positive, but they must be considered alongside comfort considerations.

Table 1. Total annual energy demand for space cooling without and with the ventilation tower effect. Data is expressed in kWh.

<table>
<thead>
<tr>
<th></th>
<th>Athens</th>
<th>Cordoba</th>
<th>Sevilla</th>
<th>Zaragoza</th>
<th>Thessaloniki</th>
<th>Evora</th>
<th>Catania</th>
<th>Foggia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without</td>
<td>4430</td>
<td>4257</td>
<td>4903</td>
<td>2563</td>
<td>3347</td>
<td>2818</td>
<td>3139</td>
<td>2700</td>
</tr>
<tr>
<td>With</td>
<td>2740</td>
<td>2253</td>
<td>3196</td>
<td>1239</td>
<td>2072</td>
<td>1483</td>
<td>1728</td>
<td>1467</td>
</tr>
<tr>
<td>Difference</td>
<td>1691</td>
<td>2004</td>
<td>1707</td>
<td>1324</td>
<td>1275</td>
<td>1335</td>
<td>1411</td>
<td>1233</td>
</tr>
</tbody>
</table>

As expected after the climate analysis, both mean and peak water consumption figures reach their maximum at Cordoba, namely 7.7 and 14.4 l/h respectively, as well as the number of hours of operation, 1499.

4.2 CO₂ and moisture content

CO₂ and moisture content levels have been estimated using IES-VE. Best practice CO₂ thresholds are between 900 ppm (CIBSE, 2006), and 1000 ppm (ASHRAE, 2004). Results of this project demonstrate how neither of these values are exceeded, being 833 ppm the peak value. According to the chosen control strategy, the PDEC system does not operate when the moisture content within the house exceeds 15 g/kg. Mean levels are between 8.41 g/kg, at Zaragoza, and 10.13 g/kg, at Catania, significantly below this threshold. If CO₂ or moisture content levels had exceeded their respective thresholds, the applicability of the proposed tower could have been limited or even nullified.

4.3 CFD results

The reliability of the CFD analysis was checked as follows. Values at the monitoring point became constant and residuals reduced to below 0.01% as required.

Boundary conditions for the CFD simulation were exported from the DTM simulation in which the air change rate was set equal to 6.3 ach⁻¹ and there is only a 4% difference between this value and the average air change rate predicted by the CFD simulations for the four cases. This means that the estimates made in the DTM are reliable. The predicted air velocities are low (fig. 2), 0.5 m/s or less, as expected in a buoyancy-driven system and temperatures are evenly distributed inside the space.
Both air velocities and temperatures are directly relevant for testing the research hypothesis. Indeed if the former had been too large or the latter too erratic, the applicability of this ventilation tower in plus-energy homes would have been significantly limited. CFD analysis has also highlighted that when most of the outlet openings are opened, there is a local warming effect due to a relevant amount of air entering through them. This does not jeopardise the effectiveness of the tower, but it generates local discomfort effects.

5. Conclusions
This project has highlighted how a ventilation cooling tower can be used to halve the energy demand for space cooling of a plus-energy home in southern Europe without jeopardising occupant thermal comfort. However, this does not mean that every plus-energy home in these regions must have a ventilation cooling tower. Findings simply suggest that it may be an efficient solution and methods for testing its performance in other buildings and locations are suggested within this study.

Limitations of the work reported here provide suggestions for further work. These may include model validation with field data, the use of a two-phase CFD model to more closely represent moisture evaporation, the use of a model of the plus-energy house in which every technological system was integrated, future climate analysis, a full economic analysis, and more analyses about what thermal conditions are acceptable for occupants within a plus-energy house.

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References


Towards Zero Carbon Homes in Europe

Ana Petrovska¹ and Luisa Brotas²

¹MSc Architecture, Energy and Sustainability, Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University, ms.anapetrovska@gmail.com
²Low Energy Architecture Research Unit, Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University, Central House, 59-63 Whitechapel High Street, London E1 7PF, UK, l.brotas@londonmet.ac.uk

Abstract
Climate change is a serious problem that mankind is facing at the start of the 21st century. Its environmental, social and economic impact has irreversible consequences and serious actions at local and global scale need to be taken to minimise its effects and recover part of the damage already done. It is well known that climate change has a major effect on the health and well being of occupants and the energy consumption of buildings. A rising awareness is now given to an increasing use of active systems for cooling and associated carbon emissions as well as the risk of overheating in buildings.


This paper examines whether the UK’s proposed standard for Zero Carbon Homes is adequate and appropriate given the foresight climatic changes in the near future for different locations across Europe.

The methodology relies on advanced dynamic building simulation software to calculate the energy consumption and thermal comfort parameters of dwellings on top, middle and ground floor of a building. The results will be presented for a series of climates and locations in Europe and using climatic predictions from 2020, 2050 and 2080 assessing the adaptive overheating criteria and looking at primary energy consumption of the different scenarios.

Keywords: zero carbon home, energy, sustainability, climate change projections, dynamic simulations

1 Introduction
The built environment is responsible for a significant amount of the energy consumption and associated carbon emissions in cities. Dwellings are responsible for almost 30% carbon emissions in the UK. The main sources of energy consumption in homes are heating/cooling, lighting, hot water (regulated energy) and appliances (unregulated energy). While technological advances have contributed to more energy efficient solutions, equipment and end-use appliances, higher living standards and people’s expectations have seen an increase of the energy use in buildings. It is clear that the housing sector plays a vital role in promoting sustainable spaces while reducing building and cities carbon emissions.

The UK Government has committed to a challenging target of reducing 80% the carbon emissions by 2050. Europe has also implemented a number of Directives designed to lead the state members towards a more energy efficient and sustainable future. The Energy Performance of Buildings Directive 2010/31/EU (EPBD recast) is the main European legislative instrument, for improving the energy efficiency of buildings. A key element of the EPBD is its requirement for ‘Nearly Zero-Energy Buildings’. (Hermelink, 2013)
2 The UK standard
UK has been pioneer in pushing energy efficiency in the built environment and securing energy supply. In 2007 the Government introduced a policy stating that all new homes must meet a Zero Carbon Standard from 2016. While the Zero Carbon definition is still open for debate, it clearly sets a move towards reducing CO2 emissions in buildings. Currently the standard only considers CO2 emissions from regulated energy use.
The first step for achieving Zero Carbon homes is obtaining a FEES (Fabric Energy Efficiency Standard), which is calculated in kWh/m²/year energy use. The second step is measured in kg/m²/year of CO2 (Carbon Compliance). A third element are the Allowable Solutions that account for the energy source and is calculated in £s. (ZCH, 2013; ZCH, 2014) The Fabric Energy Efficiency Standard (FEES) is the mechanism to account for the building and its occupants ‘passive’ interaction with the surroundings and directly affects the space heating and cooling energy demand for zero carbon homes. The amount of energy which would normally be needed to maintain comfortable internal temperatures in a dwelling can be influenced by a series of parameters: building fabric U-values, thermal bridging, air permeability, thermal mass, external heat gain (solar), internal heat gains as a result of the metabolic activity of the occupants or as a by-product of services and equipment. Recommended levels are: regulated energy level of 39 (for apartment blocks and mid-terrace homes) and 46 kWh/m²/year (end terrace, semi-detached and detached homes). (ZCH, 2014)
The Passivhaus Standard is a comprehensive low energy standard intended primarily for new buildings. This will also be used in this paper as a base for comparing primary energy consumption in dwellings. (Passivhaus, 2014).

3 Overheating in buildings
Overheating has become a key problem in building design in view of global warming. The need to reduce the energy consumption in buildings has restricted the solutions available for designing comfortable and low-energy buildings. In the last few decades, researchers have thoroughly debated building occupants' thermal responses to the combined thermal effect of the personal, environmental and physiological variables that influence the condition of thermal comfort.
The CIBSE Technical Memorandum (TM52) provides a methodology for assessing and predicting overheating in buildings in Europe. This research questions the thermal comfort of the Zero Carbon House, according to the three criteria defined in the TM 52. The building must pass at least two out of the three criteria to be compliant with the recommendations. (TM52, CIBSE 2013).

4 Project description
The project targets residential buildings through chosen typologies. The residential prototype is tested in terms of its energy performance and thermal comfort - risk of overheating. The project challenges and tests if it is valid and applicable to adopt a unique criterion for Europe: Can a single definition of a zero carbon standard be valid throughout Europe and what are the implications of that? As a result of global warming, the climatic conditions are expected to change. Therefore this research also analyses the building performance in London and the other European cities with climatic predictions for 2020, 2050 and 2080. Simulations of different scenarios, locations and climates were performed with dynamic simulation software IESVE 2014.

4.1 Climate
Different types of climates across Europe, that range from coldest to hottest locations: London – Marine, Copenhagen – Marine, Moscow - Humid Continental, Munich – Highland,
Lisbon – Mediterranean, Athens Mediterranean, have been chosen as a good representation of the climatic variety in Europe. Relevant maximum and minimum annual temperatures are briefly presented in figure 1.

Future climatic predictions in the form of weather files for the year 2020, 2050 and 2080 have been generated with the “The climate change world weather file generator” (CCWorldWeatherGen) developed by The Sustainable Energy Research Group. (CCW, 2014)

4.3 Model construction and assumptions

The building model consists of a 3-storey apartment block containing three two-bed apartments (with useful floor area 66 m²). The dwellings are located at different heights in the building: ground floor, mid floor and top floor. The building envelope characteristics are those of the prototype defined by Zero Carbon Homes (ZCH, 2009; ZCH, 2014: PartL1A, 2013) and main façade are oriented East.

The base model has an ideal (theoretical) heating system, with a heating set-point temperature of 21 °C (living areas) and 19 °C (elsewhere); Cooling is provide with natural ventilation, simulating open windows, in summer months. The model has permanent infiltration all year.

The second model has an active cooling system (with a cooling set-point temperature of 23 °C). Natural ventilation/cooling is set to operate from beginning April till end September and it is set to be in operation when the occupants are at home and dependent on the internal and external temperature difference and the cooling threshold.

Typical internal gains for lighting, people and equipment have been adopted from ZCH. Occupancy patterns have typical household occupancy schedules.

The model assumes a primary space heating and Domestic Hot Water (DHW) supplied with gas and a cooling system if existent by electricity.

5 Results

This section presents results for some typologies and locations in Europe. Further details and can be seen elsewhere. (Petrovska, 2014)

London
- The estimated total energy consumption of the flats in London is approximately 90KWh/m²/year (average of grd., mid and top floor). There is some unregulated energy (i.e. cooking) that was not modelled but this result is 25% lower that the maximum primary energy consumption of 120KWh/m²/year of the Passivhaus standard. It can be concluded that the ZCH model has a good performance for the London climate. The heating loads of a mid-floor flat are approximately 15 KWh/m²/year, also compliant with the requirement (borderline) of the Passivhaus standard.
- In 2080 a ground floor flat in London will save 34% of the total energy now spent on heating.
- The total energy consumption will slightly decrease in 2080, as seen in Figure 2, because of the significant decrease in the heating loads.
- Top floor and ground floor London flats do not show a tendency for significant overheating now and until 2080. A naturally ventilated mid floor London flat shows a high overheating risk in 2080, failing all three criteria defined by the TM 52. (CIBSE TM52, 2013). See Table 1. Other passive systems namely shading or higher thermal mass combined with night ventilation may succeed in reducing this risk and avoid the use of active systems.

![Figure 2](image2.png) Top floor London flat total system energy in KWh/m²/year

![Figure 3](image3.png) Ground floor London flat heating and cooling sensible loads in KWh/m²/year

Table 1 Mid floor London flat results

<table>
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<td>11.7</td>
<td>0</td>
<td>77.9</td>
<td>77.9</td>
</tr>
</tbody>
</table>

**Moscow**

- The total energy consumption of the flats in Moscow is approximately 120KWh/m²/year (average of grd., mid and top floor).
- The heating loads of a mid-floor flat in Moscow are approximately 44 KWh/m²/year.
- In 2080 a ground floor flat in Moscow will save almost the same as the one in London approximately 34% of the total energy spent now on heating.
- A top floor flat in Moscow will increase its cooling loads in 61% in 2080.
- The ground floor flat in Moscow spends approximately 25% more total energy than the same flat situated in London.
- Top floor and ground floor Moscow flats do not show tendency for significant overheating currently and until 2020.
- A Moscow top floor flat reaches an internal temperature of around 29 °C at present, whereas in 2080 will rise to 37 °C. See figures 5 and 6. This will be a cause of concern in terms of comfort of the occupants or an expected increase of use of active systems for cooling and therefore an increase of energy use/carbon emissions in buildings.
Athens
- The total energy consumption of the flats in Athens is approximately 84Wh/m²/year (average of grd., mid and top floor).
- The heating loads of a mid-floor flat in Athens are approximately 10.5 KWh/m²/year.
- The total system energy consumption of a mid-floor flat in Athens is 87.6 KWh/m²/year and on the ground floor flat is 83.6 KWh/m²/year.
- The top floor flat will have to spend 40% more on active cooling in 2080.
- It is interesting to see the comparison of the NV scenario in a flat in London and Athens (Figure 7 and 8), highlighting a reduction of the energy use for heating due to global warming. Colder climates in Europe will have higher savings in heating.

6 Conclusions
Because of future climate change and increased temperatures, buildings located in colder climates will benefit in future. In 2080 buildings placed in: London, Moscow, Munich and Copenhagen will be able to save energy for heating. As some will not even require cooling, the overall energy consumption will be lower. These savings will be up to 12% of the total energy consumption in the dwellings in 2080 on the locations above.
Climate change is disadvantageous for hotter climates like Lisbon and Athens in Europe, as the energy consumption for cooling will rise more than will reduce for heating. In 2080 the energy consumption will increase about 6% in dwellings at these locations.
Dwellings in London in the future will be less able to rely on natural ventilation and passive strategies to maintain comfortable indoor conditions. A naturally ventilated flat in London in 2080 will fail to deliver thermal comfort to the occupants. Therefore active cooling will be introduced to the building to keep the occupant’s comfort level within an acceptable range. This will mean more energy spent on cooling that will increase the overall energy consumption in 2080. The three most vulnerable locations in terms of satisfying the thermal comfort criteria defined by TM52 (2013) for current and future weather scenarios are: Moscow, Athens and Lisbon. The zero carbon model with the best performance in terms of thermal comfort is placed in Copenhagen. The building does not show overheating signs in present neither in future. Most of the typologies in 2080 will be overheating in several locations across Europe. The zero carbon model of a home has a good performance in terms of energy savings in these locations: London, Moscow, Munich and Copenhagen. The best location for the Zero Carbon Home looking at both energy consumption and the thermal comfort criteria (with equal weight) is London. Second is Copenhagen. In locations like Athens and Lisbon there are no predictions of energy savings because of the increased need for cooling systems. Generally, as the energy consumption depends on the fuel type consumed, and as different locations have increased/decreased demand in heating/cooling, different energy savings/consumption are experienced in different locations. Even if at first glance a place may have higher energy savings from heating than cooling, when converted with the fuel type (electricity/gas) the situation may reverse. Both fuels have different primary energy to CO2 emission conversion factors and different costs in different countries. The model of Zero Carbon Homes proposed by the UK and here simulated for different location in Europe may not be the ideal, in particular for hot climates where overheating or high cooling loads are a problem at the moment and in the future scenarios. Different strategies and building characteristics may turn to be more appropriated given a variety of climates in Europe. However it seems reasonable to adopt a common methodology in terms of a primary energy consumption or carbon emissions threshold as well as adopting similar criteria for assessing overheating, like the one proposed by TM52.

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In Support of Willingness to Change Energy Consumption Habits

Richard Bowman
MSc Sustainable Building Performance and Design, Oxford Brookes University, UK
13087288@brookes.ac.uk

Abstract
Behaviour in the home contributes to 50% of the energy consumption of the home. The study explored moderation of participant behavior and her willingness to adopt sustainable energy consumption habits. The study builds on DEFRA's research that established behaviour change as necessary to achieve a sustainable society. However studies of willingness to change are not evident. Policy continues to support Jevons Paradox that energy efficiency will not reduce energy demand. The study adapted a behavioural change tool developed by Stanford University's Persuasive Tech Lab. Community based social research recorded three sets of data; firstly, participant demographic and house-choice behaviour, secondly, participant environmental intent, attitude and behaviour, and thirdly participant willingness to change energy consumption habits. This study suggests attitudes changed to a motivated and willing state. The study proposes adapting the 'Behaviour Grid' for designers to motivate and raise a person's ability in support of willingness to undertake behaviour change.

Keywords: Energy, behaviour, habit, willingness, change.

1. Introduction
Behaviour in the home contributes to 50% of the energy consumption of the home (Sorell, 2009). While society's attitude and awareness surrounding energy-use has changed, energy-use behaviours appear to have not. There are two concerns with society's ability to consume less and differently in order for efficiency gains to be effective. Firstly, common policy assumed that sustainability through energy efficiency would reduce energy demand (Herring & Sorrell, 2009). In 1980 Khazoom and Brookes postulated further on Jevons Paradox of 1865 in support of neo-classical growth theory surrounding micro-economic supply and demand; efficiency reduced cost that supported growth. This led to an increase in the use of growth's associates and dependencies such as energy, which conflicts with a sustainable, equitable and just society. The second concern lies with the gap between a person's decision making surrounding her ethical consumption and her behaviour. A person's consumption actions are both a means and end, embodying her values and social actions out of convenience for comfort and cleanliness in the pursuit of a contemporary natural purity (Herring, 2009). A person's value-action gap is motivated by self-interest, social norms, habits, desire, approval, sacrifice, behavioural modes and concern for the common good. These two concerns contribute directly to the rebound effect in efficient home energy use, whereby a person more frequently maintains a higher level of thermal comfort for longer (Sorell, 2009). This places the designers of energy efficient buildings in a somewhat paradoxical position; are designers of energy efficient products, such as buildings, providing a solution or contributing to the problem and maintaining the status quo? If attitudes have changed, and behaviour has not, then is a person now actually more willing to live sustainably? How do designers support this willingness to change across their own ethical creative Value-Action Gap?
2. Background

This section has two aims: (1) to provide a short critical review of research to date, and (2) to provide a brief critical examination of factors surrounding the issue.

2.1. Frameworks, Attitudes and Behaviours

In 2007 the Department of Environment, Food and Rural Affairs and the Department of Trade and Industry concluded energy consumption in the home as the dominant area where a person's behaviour has the most negative environmental impact. Through a diffusion of responsibility, sustainable lifestyle was considered effortful and costly, with lifestyle choice seen as not contributory to climate change. The research suggested a person felt her individual liberty and freedom would be infringed upon in a less individualistic pursuit of a sustainable society. However a significant minority maintained that addressing the risk of climate change should be high on the national agenda. UK policy attitude shifted from how to support a person's energy consumption lifestyle to concern with her energy consumption behaviour within her lifestyle. Analysis of barriers to lifestyle change determined DEFRA's seven population segments, which ranged from the 'positive greens' through to the 'honestly disengaged' that defined a particular policy response. The 2008 Queensland TRED Program identified 241 discrete residential energy-use behaviours that address hot-water energy, appliances, entertainment, hygiene, thermal comfort, renewable energy, retrofit and construction (McKenzie-Mohr, Hargroves, Desha, & Reeve, 2010). A brief view of the Townsville Residential Energy Demand Program attributes 10% maintenance, 35% to design and 55% to the occupant to affect energy-use behaviour change, as illustrated in Figure 1 below.

![Figure 1 TRED Discrete Behaviours Distribution](image)

Of the 30 one-off, habitual, regular or occasional behaviours identified by DEFRA, 18 were attributed to in-the-home behaviours, and 12 were considered to be 'headline' goals. Subsequently 3 one-off, 1 habitual and one occasional behaviour were promoted through policy; insulation of the home, micro-renewable energy generation, GETs, energy management and energy efficient products respectively (DEFRA, 2007).

2.2. The Challenge of Needs, Wants and Consumption

Attaining a sustainable society through changes in technology and its use in households must also focus on change in habitual behaviour that maintains social norms in fulfilling acceptable needs, but not wants. To meet her needs and maintain dignity a person requires food, clothing, accommodation, utilities and fuel, as well as household goods, personal goods and services, transport and activities that are social and cultural (Druckman & Jackson, 2012). Increasingly needs are subjected to obsolescence that exploits a persons dissatisfaction and informs her social context through the sign-value of manufactured objects that increase the rate of consumption.
Reinforced through incentives, institutional barriers, and inequalities of choice, as well as habit, routine, social norms, expectations and values, a person's consumption has increasingly preceded her production in support of the debt based economic system (Baudrillard, 1996; Jackson, 2005).

2.3. Promoting Sustainable Behaviour
A person rarely acts out change in isolation as her acts are governed by peer-reviews of her values, beliefs and actions pertaining to social acceptance, which makes what may be perceived as delinquent behaviour, difficult on her part. A person is also a persuader and therefore contributing arbiter of social acceptance. It is this reflexive social interaction that is able to provide conspicuous consumption with a questionable status in contemporary transitional society. It is within this environment that it is possible to persuade a person to think through the implications of her energy use behavior (Corner, 2012). A person motivated to critique her behavior presents the opportunity to persuade in favour of change.

2.4. The Problem with Persuasion
The criticism of separating the person from her community is that this is seen to avoid addressing the complex dynamics of personhood in society, while assuming she has a capacity for action relevant to sustainable living which is more than reality provides (Brynjarsdottir, Hakansson, Pierce, Baumer, DiSalvo, & Sengers, 2012). A person’s behaviour is a compound of elements that form her sense of self, considered too complex to be tailored to a narrow view of sustainability, human behaviour and their interrelationship (Brynjarsdottir, Hakansson, Pierce, Baumer, DiSalvo, & Sengers, 2012). Modernist values of calculability, predictability, efficiency and control entailed a reductionist view of sustainability being taken into account when constructing persuasive arguments for behaviour change. Governments, NGO’s, business, media and individuals alike continued with sustainability communications that range from the fear inducing to greenwash that disempower a person's due consideration of a sustainable lifestyle given the threat of climate change.

2.5. Persuasive Systems for Sustainable Behaviour
A person is persuaded to socialise in increasing degrees through persuasive social media in various architectural settings, designed for salient self-shaping and commitment change with or without a person's knowledge (Moraveli, Akasaka, Pea, & Fogg, 2011). The Stanford University Persuasive Tech Lab recognised that a combination of a trigger with a person's motivation level and ability achieved measurable success through small step-changes that approximate the overall objective of lifestyle change (Fogg, 2009). Fogg drew on two traditions in psychology: (1) Social Cognitive Theory, Mindset and Attribution Theory, and (2) the Transtheoretical Model. The Fogg Behaviour Model defined types of behaviour change against time frames that are associated with a particular psychology and persuasion strategy for a persuasive technique to be mapped against. Fogg used simplicity as a means to increase ability so that whenever a person's motivation and ability placed her above her activation threshold, the correct trigger empowered her to do extraordinary and difficult things in order to change her behaviour.

3. Field Research Method
This study and prior research by DEFRA focused on suburban areas. DEFRA drew on four distinct geographic locations with 114 participants engaged (Brook Lyndhurst, 2007). A questionnaire was personally distributed equally amongst a random population sample in six residential areas of a single town to account for different
attitudes and house types. Each area was seen as representative of the post-war architectural and economic period. The questionnaire was divided into three subsections: (1) the participant demographic and housing choice behaviour, (2) the participant’s lifestyle fit with her environmental attitude and intent towards the environment and sustainable lifestyle, and (3) the participant’s willingness to consider small step-changes to daily habits. The tests for willingness by this study adapted Fogg’s Behaviour Model and defined as do you or would you do it if you could... for either one-time, one-time leading to an ongoing obligation, for a period of time, on a predictable schedule, on cue, at will or always. Each was considered in terms of familiarity, frequency, intensity and duration or stop and cease. This defined 35 small step-change catalytic behavioural goals. Although a response to a broad view of sustainability was asked for, specific statements tested Energy Performance Certificates, space heating, lighting, insulation, solar thermal energy and cost. Research variables not directly attributed to energy-use inform as to psychological attitudes surrounding energy-use in the home. The Likert-scale measure for willingness was considerable (1), moderate (2), some (3), little (4) or no interest (5). Of the 240 participants engaged, 88 returned responses at a time when energy security and ‘fracking’ in the UK was prominent on the national agenda during a period of particularly hot weather.

4. Findings

The engaged sample population was broadly representative of the UK population recorded by the ONS Census of 2011 and well educated and affluent. Results suggest that since 2007 participant-declared attitudes changed in favour of a more positive environmental behavioural attitude illustrated in Figure 2 below.

Cycling through the schedule-dependent behaviour goals as shown in Figure 3 below, revealed an increased change in willingness from some interest to moderate interest.
68% of participants were unaware of the annual energy consumption in their home, and 14% of participants unaware of their monthly energy bill, however 57% support home EPC for informed future decisions regarding house purchasing.

Figure 4 Participants Behavioural Goal Interest

Of the 35 behavioural goals proposed, 37% registered considerable to moderate willingness, and 44% some willingness across the population segments as illustrated in Figure 4 above. The measures of central tendency surrounding willingness behavioural goals might be considered equitable across the population segments.

Figure 5 Willingness Behaviour Goals Measures of Central Tendency

Analysis shown in Figure 5 above reveals an opportune level of motivation whereby behavioural goals always performed returned a mean willingness of 2.17, on-cue 2.43, predictable schedule 2.63, at-will 2.64, one-time 2.68, for a period of time 3.17 and one-time leading to obligation 3.61. Cessation behavioural goals returned a mean willingness of 2.54, increasing the behaviour frequency, intensity or duration 2.69, existing or familiar behaviour 2.81, new or unfamiliar behaviour 2.83 and decreasing behaviour 2.94. Discussion surrounding the significance of each goal is beyond the scope of this document. In summary obligatory and periodic goals entailed a commitment to improving social capital, and decremental goals entailed sacrifice, while familiar or incremental goals on cue are seen as the most favorable.

5. Conclusion

Previous reductionism poorly framed value held in behaviour change by limiting the view as to what entails value in sustainability, undermining the complexity of reducing energy use in the home, which is contingent upon habitual change by the occupants. The needs of a person have undergone changes that have affected a change of energy use habit, and influenced by obsolescence in the social domain, individualistic barriers to change remain in place. This study suggests that the motivated state person's has also changed. In response, designers can choice-edit in
support of the motivation state of persons to adopt small catalytic sustainable modes of change. Designers and producers possess the means to overcome barriers to individual change through reflexive social interaction. By striving for stronger pro-environment construction legislation and choice editing out the means for poor habitual energy use, it is possible to make effective small energy-use step changes well. The semantics of the framework behaviours require increased focus and refinement in order to inform design decisions to match the behaviour change; this study is seen as a new method for thinking about, and designing around, energy-use behaviour in buildings. This will entail further discussion and comparison of supporting willingness to change in favour of greater social capital and sustainable energy-use behaviours.

6. References
How does a well-insulated building, during a UK heat wave, perform in comparison to its predicted performance

Simon Phillips¹, Chris Iddon², Malcolm Cook³

¹ MSc Low Carbon Building Design and Modelling, School of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, UK. s.l.phillips-09@student.lboro.ac.uk
² SE Controls, Hood Innovation Centre, Wellington Crescent Lichfield, Staffordshire, WS13 8RZ UK. chris.iddon@secontrols.com
³ School of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, UK. malcolm.cook@lboro.ac.uk

Abstract
A combination of data analysis and computer simulation has been carried out to investigate the effects that UK heat waves have on naturally ventilated, highly insulated buildings. The work originates from the hypothesis that an increase in insulation levels in modern design and construction (to reduce energy, costs and carbon emissions) has the potential to cause detrimental effects on the internal environment. The building studied is a newly constructed, naturally ventilated secondary school in the UK. Dynamic thermal simulation software was used to model the school using a Design Summer Year and morphed data based on data collected from site. Measured data and simulation results were compared to validate the model, which was then used to explore the effects of future, higher temperatures. The study demonstrates how naturally ventilated, highly insulated buildings risk overheating or could lead to the need for hybrid/mechanical ventilation to manage hotter periods of the year.

Key words: Insulation, Natural ventilation, Heat wave, School, Dynamic thermal simulation

1 Introduction
Current data shows that the UK is experiencing more extreme weather events, which are thought to be as a consequence of climate change (IPCC, 2014). This affects the performance of our buildings; and in some cases the conditions that the construction was initially designed for no longer exist resulting in the need to change or adapt. Recent low energy building design has emphasised the importance of high thermal mass and high levels of insulation in order to reduce heat loss in the winter and impede heat transmission into the spaces of the building during summer. In order to save energy many larger public and education buildings are now being designed without mechanical ventilation. Instead natural ventilation strategies are in place to maintain a comfortable and healthy environment and are designed and tested against warmer weather files, but not extreme weather conditions or temperatures. For this reason there may be a safety and welfare risk to the buildings users if such events occurred. The balance of energy use against the comfort within the building becomes more important when the users health and well-being is at risk, not just their comfort. Periods of above average temperatures for prolonged periods of time (heat waves) have been experienced in the UK in the last decade. With changes in global temperatures ‘overheating is a growing concern in UK schools and is likely more so
in the context of a warming climate’ (Montazami et al, 2012). The aim of the work reported here was to quantify the effects of failing to deliver naturally ventilated buildings that perform as designed (in terms of indoor air quality, thermal comfort and energy use) during periods of extreme hot weather. There is a need to objectively define and quantify a ‘UK heat wave’ in order to inform industry, and enable better analysis of post occupancy data. Highly insulated buildings are more vulnerable to overheating if care and attention is not given to adequate ventilation. Analysis of data by the authors found that a building of this type can be affected by higher than normal temperatures up to three weeks after a heat wave has ended before temperatures return to normal. This puts not only the health of vulnerable users (children) at risk, but can affect their learning capabilities and future potential. Schools may have an unorthodox relationship between occupation pattern and occupation density but this doesn’t mean that the total time spent in them is any less than other types of buildings. Children and teachers are in the rooms at a high density per unit floor area for a maximum of two hours at a time, and then move to other rooms in the same building. This therefore means that the temperatures within each space must firstly not exceed any design parameters; this includes not having a difference larger than 5°C from the breakout spaces, other classrooms and, the external environment.

2 Naturally ventilated, thermally massive and highly insulated buildings

There is a shift in school designs towards high levels of insulation to reduce energy costs and carbon emissions; but there is limited research in the effects that the same buildings have on their indoor environment if brought close to failure and overheating. Educational buildings have larger consequences when underperforming in a heat wave because of the vulnerability of its occupants, primarily children. If lower temperatures are maintained in classrooms, it has been found to improve pupil’s academic performance on average by 5.7% (Wargocki et al, 2007). Academic performances and grades were increased when the pupils were taught and tested in 22.5°C rather than 26°C. There is a complex relationship between a buildings construction, services, occupancy and the climate in which it stands. All characteristics affect the performance of the building, but none less than the fabric during periods of excessively hot weather. From global warming and climate change it can be assumed that the future weather will be different to the conditions that we currently experience.

2.1 Heat waves

There are many variations but no objective heat wave definition, due to their multiple criteria (temperature, duration, time of year, location, peak and diurnal swing). The following definition has been chosen because it is best suited to the study being considered here and contains all key elements found in the definitions in literature: a stated duration of day, an acceptable and valid baseline comparison and the suitable objective average with no subjective components; “A period of 5 consecutive days, when the daily mean temperatures are above the 95th percentile of the whole year’s temperature distribution when compared to the baseline temperatures of the previous 30 years”. With this applied to the data from the building considered here, the heat wave was identified as between 08/07/2013 and 02/08/2013 as can be seen from figure 1 where the 2013 daily average temperatures exceeds the 95th percentile of the 1961 to 2011 baseline.
2.2 Building Data Analysis

The temperatures experienced in the summer of 2013, identified as a heat wave, raised the internal temperatures and in turn affected the users comfort. Prior the heat wave the thermal mass absorbs excessive heat in order to maintain a more constant temperature internally; the materials that can absorb heat, store it and release it later (Yang et al., 2008). As the heat wave continued the thermal mass was not able to act passively due to no potential to cool down because of persistent high temperatures fully loading the structure with heat energy. Under dynamic conditions thermal mass and thermal insulation are ‘rather complicated and interactive’ (Al-Sanea et al, 2012) which is what wider thermal characteristics are founded upon. In steady state, thermal mass is able to increase the energy storage of a building so to reduce the effects of thermal transmittance while still enabling the provision of necessary thermal comfort. But it cannot make substantial reduction on the daily transmission load of a building. To reduce this, an increase in thermal insulation is required (Al-Sanea et al, 2012) (Yang et al, 2008) (Montazami et al, 2013). The use of insulation though is a ‘double edged sword’ (CIBSE, 2005); it can prevent a building from losing heat, but in hot weather this can increase the risk of overheating. During a heat wave large diurnal swings occur and therefore result in the demand for a larger cooling load. The higher temperatures cause the buildings to ‘reside for many hours at high room temperatures’ (Henze et al, 2007). Because the thermal storage potential is reduced during this period, the thermal comfort criteria may be violated. The storage capacity of thermal mass enables heat to be absorbed in the hot days and released in the cooler evenings, using nighttime ventilation. The use of thermal mass in a building can reduce peak heating or cooling loads, temperature fluctuations (Asan et al, 1998), and subsequently the building energy consumption. The analysis of the data collected from the school in this study found that the building was able to delay the effects of external temperatures up to two days in normal conditions. But following periods of prolonged warmer weather and heat waves, the same building types have a reduced lag and reduced effect in lessening the extremes of the external temperatures. The school’s occupation when in a heat wave did not affect its performance in comparison to the effects that external factors imposed. The building studied is a three storey building made up of 4 radial wings emanating from a central core area. This study focusses on data collected from 5 rooms GF-E (ground floor east facing), FF-N (first floor north facing), FF-S (first floor south facing), FF-E (first floor east facing) and FF-W (first floor west facing). Data was collected during the summer of 2013,
an educational building with use of the SE Controls NVlogiQ™ system. Two of the
five rooms (GF-E and FF-S seen in Figure 2) exceeded the 5°C average internal-
external temperature difference referred to in BB101. This is due orientation,
insufficient shading and exposure to direct solar gain.

Prior to the heat wave all rooms displayed standard diurnal curves in regards to their
orientation, but after a single week into the heat wave this curve mirrors the external
temperature because the mass and insulation is now having no effect. During the heat
wave the average daily temperature in each room has been measured. On one day
(19/07/2013) these averages ranged from 23°C to 30.2°C which is a 7.2°C difference,
between two internal spaces. This is 2.2°C greater than the allowable 5°C internal to
external average temperature difference stated in BB101. Thus, moving between the
rooms would therefore result in a noticeable difference in temperature. Moving
between the rooms would therefore result in a noticeable difference in temperature.
Up to three weeks after the heat wave all the rooms displayed weekly diurnal curves
with ±0.5°C variation. This flat profile continued as the building recovered from the
heat wave before returning to its regular temperature profile.

2.3 Model Validation and Simulation
The school building was accurately modelled in IES VE software from architectural
and consultants details. This was used to simulate summer period and the results
produced where then analysed in terms of the buildings performance in future
climates. Validation of the model compared the data collected to the morphed weather
file (a mirror of the 2013 heat wave) used in the simulation. The dynamic thermal
simulation model was considered accurate when the following conditions were
satisfied:
A. No single space average exceeds a difference of 2°C, and
B. No single space average exceeds a difference of 10%.
C. No whole simulation model average exceeds a difference of 1°C, and
D. No whole simulation model average exceeds a difference of 5%.

Table 1 Simulation results showing temperature (°C) in each space modelled

<table>
<thead>
<tr>
<th>Rooms</th>
<th>Heat wave</th>
<th>Current TRY</th>
<th>Current DSY</th>
<th>2030 TRY</th>
<th>2030 DSY</th>
<th>2050 TRY</th>
<th>2050 DSY</th>
<th>2080 TRY</th>
<th>2080 DSY</th>
</tr>
</thead>
<tbody>
<tr>
<td>T ext</td>
<td>Max</td>
<td>28.70</td>
<td>24.70</td>
<td>28.60</td>
<td>30.40</td>
<td>30.80</td>
<td>31.9</td>
<td>32.80</td>
<td>30.80</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>6.50</td>
<td>3.80</td>
<td>7.20</td>
<td>7.30</td>
<td>7.60</td>
<td>9.90</td>
<td>10.20</td>
<td>12.00</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>16.97</td>
<td>15.36</td>
<td>16.13</td>
<td>18.52</td>
<td>19.42</td>
<td>19.77</td>
<td>20.72</td>
<td>21.44</td>
</tr>
</tbody>
</table>
The 2013 heat wave was found to be warmer at the height of summer than the future weather file 2030 DSY. This therefore implies that current buildings that have been designed with the aid of such simulation techniques and technology may not sufficiently perform (providing adequate regulatory indoor temperatures to all its users in all its spaces) in current day weather extremes. By 2050 all five rooms were found to have exceeded all three BB101 criteria. Buildings that underperform in today’s summer weather conditions will provide even worse conditions in the future.

### 3 Conclusion

Thermally massive and highly insulated buildings can only have their desired effect (increasing time lag and lessening the extremes of temperature) if the correct nighttime purge/ventilation strategy is employed. Failure to do so can result in a negative effect on the conditions of the internal environment. The structure of the building releases the heat at night into the spaces and therefore creates a larger load for the following morning to react to. This can result in undesirably high internal temperatures in the morning following a hotter than average day previously. In order for naturally ventilated, highly insulated and thermally massive building to recover from a UK heat wave it requires up to 3 weeks of lower than average, average and normal temperatures. During these three weeks the internal temperatures can be expected to remain at the same temperature throughout the day and night. Therefore usually (independent to the dry bulb temperature of the three weeks) the standard diurnal swing is not experienced while the building recovers from the heat wave. There will be no shape or pattern in the temperatures Instead a constant temperature fluctuating no more than $\pm 0.5^\circ\text{C}$ is likely to occur. This is believed to be because the structure of the building is releasing the energy stored during the heat wave, therefore cooler periods are warmed by this release, and warmer periods are maintained by external factors. Future designs of educational buildings must focus on the effects that external factors have on their performance rather than the internal loads from equipment, occupants and lighting. Within BB101 are criteria regarding the difference between the external temperature and internal temperature; and that this should not exceed an average of $5^\circ\text{C}$. But from this project it has been seen that there are differences in temperature of $>5^\circ\text{C}$ between internal spaces. This therefore would result in a larger effect on the occupants’ comfort when moving around the building than in/out of the building. This difference between internal spaces in temperature extremes, normal building performance and future climates has the potential to be developed into a new standard to which building types where occupants move around
often are designed, critiqued and analysed. In order to future proof the designs of naturally ventilated, highly insulated and thermally massive buildings to sufficiently perform there needs to be high level analysis regarding insulation levels so that the construction does not put the building at risk of overheating in hotter periods of the summer. A reduction in insulation may increase the winter heating costs but could be outweighed by the reduced summer cooling demand.

References


Design of a self-sufficient homestead using permaculture design techniques and low-impact building materials in Punjab, India

Digvijay Rajdev

1 MSc Sustainable Architecture Studies; University of Sheffield, UK
rajdevdigvijay@gmail.com

Abstract
The research aims to provide a solution to the alarming increase of unsustainable buildings in India. The majority of buildings in India are built using materials with high embodied energies like brick and concrete, and incur huge running costs because of their exorbitant heating and cooling loads. The paper will first investigate the availability of various low-impact building materials around the design site and then suggest the most appropriate material for construction of the homestead suitable to the site’s climatic conditions. It will also propose a new technique of integrating permaculture with architecture by providing a methodology to produce industrial hemp at site. The self-sufficient homestead shall be designed using passive house design strategies so as to minimise its ecological footprint. The design proposal will act as a pioneer for low impact buildings in India and also serve as a base for further research in this context.

Keywords: Low impact building materials, Hempcrete, Permaculture, Self sufficiency

1 Introduction
Founded by Bill Mollison and David Holmgren (1988), “Permaculture (Permanent agriculture) is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems”(p.ix). Ever since the inception years, most of the Permaculture designs have been limited to agriculture. This design of a self sufficient homestead in Punjab, India using will be a prototype for India which would also help in bridging the gap between architecture and permaculture.

1.1 Site
Location: Mamupur (30°46'7"N 76°35'1"E), Punjab, India
Total area: 4 acre/1.6 hectares
Soil type: Fertile agricultural land

1.2 Climate
Punjab experiences five seasons throughout the year namely summer (mid-April to end-June), monsoon (July to mid September), autumn (mid-September to mid-November), winter (mid-November to mid-February) and spring (mid-February to mid-April). The site has a humid subtropical climate with scorching summers, cold winters, unreliable rainfall and great variation in temperature (-1°C to 46°C).
2 Material Mapping

2.2.1 Earth
Earth clay can easily be acquired from the bank of the Satluj river which flows 22km away from the site.

2.2.2 Hemp
Ever since the eighth century, Hemp is cultivated in India as a fibre crop and is grown in Punjab as a wild weed (Pawar, 2014). In the state of Uttarakhand, the government has allocated 30,000 hectares of land for industrial hemp farming (Pioneer, 2010). Hemp is cultivated around 160 kms away from the site by the Pabila community in Garhwal and Kuthliya Bora in Kumaon of Uttarakhand for making blankets, quilts and ropes (Tribune, 2008). The Chad village of Kullu valley in Himachal Pradesh which is around 240 kms away, also cultivates hemp for making slippers. The villagers in Uttarakhand, Kashmir and Kerala have been producing hemp for its fibre and medicinal value for a very long time.
2.2.3 Straw
Punjab being an agricultural state of India, produces close to 22% of country’s rice and 55% of wheat every year (PEDA, 2007).

2.2.4 Lime
The nearest lime stone reserves are found in Himachal Pradesh- 40 km away, Uttarakhand -120 km away and Rajasthan -200 km away. Hydraulic lime can easily be acquired from the suppliers in Mohali city which is 14 km away from the site.

2.2.5 Timber
The shiwalik range of lower Himalayas is the home for Deodar trees, which are 40 km away from the site. The use of Deodar wood for construction is very well known in state of Punjab because of its durability.

3 Methodology

3.1 Design Process
Permaculture is an ecological design process (P. Asso., n.d.) in which the designers work along with nature instead of going against it.

Sector planning and zoning are two aspects of Permaculture design. In order to

maximize the energy efficiency, activities are put in different zones, depending on frequency of use, maintenance and visits.

In Fig. 3 above, Zone 0 is the area where people live and have their respective home. Zone 1 includes areas around the house which need continuous observation like a kitchen garden. Zone 2 includes less intensively managed areas like a chicken coop where the residents need to visit once every 3 or 4 days. Zone 3 includes areas where the inhabitants visit once every 15-20 days like fruit tree plantation areas. Zone 4 and Zone 5 are for wild and unmanaged areas respectively.

In order to acquire the building materials, either an extra external zone 6 could be added to these existing zones or building materials could be grown on site in an integrated manner. An integrated method of acquiring materials will be better as it will reduce the carbon emissions of these materials which could be designed in the following way:

![Figure 3. Permaculture-Zoning Design Process. ©The Resiliency Institute](image-url)
3.1.1 Hemp-Permaculture

Figure 4. Zonal planning for acquiring low-impact materials

ZONE 0: Cultivation of hemp at site (6 months)  
ZONE 1: Timber plantation area (40 years) and Earth  
ZONE 2: Limestone quarry areas (1 million year)  
ZONE 3: Limestone and timber

Because hemp is being cultivated around 120 kms away from the site, I shall cultivate hemp at the site (1.6 hectares) and use the same hemp in constructing the homestead by making Hempcrete. Hemp will be acquired from zone 0, timber and earth from zone 1, and lime from zone 2. This method will further reduce the carbon footprint of the homestead as all the building materials will be manufactured and transported with negligible embodied energy.

3.1.2 Hemp Plantation in Zone 0

According to Paul Benhaim (2010), Clay Soils/free draining sandy or clay loam soils are the best type of soils for growing Industrial Hemp. The soil type available in Eastern Punjab is Grey Brown Podzolic Soil which has a fertility of medium to low and the texture is loamy to clayey.

3.1.3 Material Estimate

According to Klara Marosszeky (2010), “if you are growing hemp just to build an average 3 bed home for yourself then you would need to grow a minimum of 1 hectare of hemp. From that you would get enough fibre to build a moderate dwelling and maybe a small shed” (p.89). According to an estimate by Hemp Foods Australia (n.d.), a 135 m² house with 200 mm thick walls could be built with 200 mm thick walls can be built with 2.2 tonnes of hemp. Also they state that one hectare of hemp can yield 7.5 tonnes of hemp (Benhaim, 2010). In the book by Bevan and Rachel (2008), they state that one hectare of land can give a yield of 7-10 tonnes of hemp.

After comparing the above mentioned materials estimates, planting the entire site of 1.6 hectares with hemp can give approx. 11-15 tonnes of hemp which will be more
than enough to construct the hemp-stead. As shown in the timeline below, the entire house can be constructed in 9 months.

Figure 5. Timeline for constructing the Homestead - 9 months

Figure 6. Master Site Plan- Before & After building the Hempstead

5 Conclusion
The aim of this research was to investigate the process to design a self sufficient homestead in Punjab, India using permaculture design principles and low-impact building materials. After researching, it was found that permaculture has a holistic design process which inculcates a number of design techniques. The humid
subtropical climate of the site demands a building material which would be insulating enough to tackle the great variations in temperature and resist attacks from termites. Hempcrete (mix of hemp shiv, lime and water) is the most appropriate material for the homestead because it is resistant to termites and fire, maintains standard indoor temperature, insulates sound and is breathable material because of its hygroscopic properties. The zoning design process of permaculture enables the user to maintain different zones around themselves depending on the frequency of use. This zoning design process can be used to acquire hemp for the homestead by cultivating it on the site itself. In a period of 4/5 months, the industrial hemp required for the site can be cultivated, harvested and processed to produce the hemp shiv required for constructing the homestead. The load bearing timber structure can be built using the timber acquired from Shiwalik hills and Hempcrete can be used for insulating the timber structure. A lime render on the walls from outside will provide protection from rain, and earth render from inside will enable breathable walls for the residents. This self-sufficient hemp-stead will be a zero carbon house as it will be built using materials with negligible embodied energy.

6 Bibliography


The Potential of Hybrid Photovoltaic-Thermal Solar Collectors: Matching Demand with Supply in Mauritius

Raheel Bokhoree¹, James Allan² and Zahir Dehouche³

1 Student: MSc Sustainable Energy Technologies and Management, College of Engineering, Design and Physical Sciences, Brunel University London, UK, bs13reb@my.brunel.ac.uk;
2 Student: EngD – Performance Testing of Thermal and Photovoltaic Thermal Solar Collectors, College of Engineering, Design and Physical Sciences, Brunel University London, UK, james.allan@brunel.ac.uk;
3 Supervisor: MSc Course Director (Sustainable Energy Technologies and Management), College of Engineering, Design and Physical Sciences, Brunel University London, UK, zahir.dehouche@brunel.ac.uk

Abstract
It is very unlikely to contain and transport the heat generated at a particular location for use at another. Therefore, it is ideal to use the heat produced close to the site of generation. The residential sector is considered the most suitable application of hybrid photovoltaic-thermal (PVT) solar collector considering that its energy output closely resembles the energy demand profile.
The paper involves carrying out a literature review of the PVT technology and analysing possibilities of integrating the PVT technology into the household system in Mauritius through experimental analysis to investigate the performance of the PVT module and software simulation in respect to covering all of the domestic hot water (DHW) needs and part of the electricity needs of typical household loads in Mauritius where space heating is dispensable. It also includes a financial analysis and indicates the reduction in carbon dioxide emissions by implementing the PVT system in Mauritius.

Keywords: Hybrid Photovoltaic-Thermal (PVT) Solar Collector; Electrical and Thermal Efficiency; Energy Demand and Supply; Domestic Hot Water; Electricity

Introduction
It is historically proven that there is a close link between the energy supply and economic development. Energy serves as a major driving force to boost the economy of a country and improve the lifestyle of its citizen. The actual number of barrels of crude oil consumed per day globally is 85 millions which is foreseen to rise to 123 millions by 2025 (Tyagia V.V., Kaushik and Tyagib S.K., 2012). A significant gap between the future energy supply and demand is therefore expected. The Kyoto Protocol has predicted a 50% reduction in the actual global oil reserve by 2050 in the aftermath of the tsunami disaster in Japan in 2011 that led to nuclear calamity which forced talks to be put into contest anew about the wide-ranging sources of energy and the universal energy security following the ever increasing tendency oil usage (Cucchiella and D’Adamo, 2012).
Griffith et al. (cited in Zhu, Tao, and Rayegan, 2012) suggested that buildings and their operations are responsible for a third of the total energy consumed globally. As a result of urbanisation due to population rise, the energy consumption and greenhouse gas emission will keep on increasing in this sector such that it will exceed that of the transportation and industry sectors. At present, the main sources of energy are the fossil fuels - comprising 81.6% of the total energy consumption - that are non-renewables and that will eventually run out. Also, they release considerable amount of pollutants that are major causes of global warming, ozone depletion and climate change. Accordingly, relevant policies and laws are being amended by several countries for better environmental conditions and improved energy savings measures (Cho, Hong and Seo, 2014).

Background
The main source of energy, the petroleum products, are imported from abroad due to the lack of oil, natural gas or coal reserves in Mauritius to be able to accommodate its energy needs (Ministry of Energy and Public Utilities, 2014). An action plan was set up in 2008 to face the challenge of producing and consuming energy in a sustainable manner. The idea was to cater for the energy needs of the population as much as possible through alternative ways, such as new technologies and fuels which satisfy the local conditions, while keeping the energy supplies fairly constant and the overall cost and environmental harm as minimal as possible (National Programme on Sustainable Consumption and Production for Mauritius, 2008).

Methodology
The methodology consists of experimental testing and software simulation. The former involved investigating the performance of a commercial PVT system by changing the parameters of the system such as solar irradiance, fluid inlet temperature and mass flow rate of the fluid and then measuring the electrical and thermal output in order to find the temperature coefficients ($\beta$), overall heat loss coefficient ($U_L$) and the heat removal factor ($F_R$) of the PVT panel. The second part involved modelling the performance of the PVT system in TRNSYS under the Mauritius weather conditions and matching the typical household loads in Mauritius with the energy output of the PVT collector.

The main aim of the experimental approach was to investigate the performance of a commercial PVT hybrid collector and to find out the values for the parameters $\beta$, $U_L$ and $F_R$. Apart from the panel performance’s characterisation, these parameters would be needed to run the TRNSYS simulation in order to model the performance of the PVT system under the Mauritius weather conditions and to match the typical household loads in Mauritius with the energy output of the PVT hybrid collector. The TRNSYS simulation involved investigating the performance of the commercial hybrid PVT collector in TRNSYS in respect to covering all of the domestic hot water (DHW) needs and part of the electricity needs of a typical household load in Mauritius where space heating is dispensable.

Results & Discussions
The outcomes of the experimental and software analysis include the results of the performance of the commercial PVT module and its energy output after having carried out tests in the laboratory and having modelled the performance of the system in TRNSYS, respectively. The results of the experimental testing and software simulation as well as that of the reduction in carbon dioxide emissions and financial analysis have been illustrated in this section.
Experimental Analysis

• Efficiencies

<table>
<thead>
<tr>
<th>Solar Irradiance, ( G ) (W/m(^2))</th>
<th>890</th>
<th>955</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Efficiency, ( \eta_{el} ) (%)</td>
<td>10.83</td>
<td>11.01</td>
</tr>
<tr>
<td>Thermal Efficiency, ( \eta_{th} ) (%)</td>
<td>61.79</td>
<td>57.59</td>
</tr>
<tr>
<td>Overall Efficiency, ( \eta_o ) (%)</td>
<td>71.16</td>
<td>67.12</td>
</tr>
</tbody>
</table>

Table 1. Effect of solar irradiance

<table>
<thead>
<tr>
<th>Mass Flow Rate, ( \dot{m} ) (kg/s)</th>
<th>0.009</th>
<th>0.018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Efficiency, ( \eta_{el} ) (%)</td>
<td>9.87</td>
<td>10.58</td>
</tr>
<tr>
<td>Thermal Efficiency, ( \eta_{th} ) (%)</td>
<td>44.08</td>
<td>44.23</td>
</tr>
<tr>
<td>Overall Efficiency, ( \eta_o ) (%)</td>
<td>52.62</td>
<td>53.39</td>
</tr>
</tbody>
</table>

Table 2. Effect of mass flow rate

<table>
<thead>
<tr>
<th>Fluid Inlet Temperature, ( T_{fi} ) (˚C)</th>
<th>25</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Efficiency, ( \eta_{el} ) (%)</td>
<td>11.01</td>
<td>10.58</td>
</tr>
<tr>
<td>Thermal Efficiency, ( \eta_{th} ) (%)</td>
<td>57.59</td>
<td>44.23</td>
</tr>
<tr>
<td>Overall Efficiency, ( \eta_o ) (%)</td>
<td>67.12</td>
<td>53.39</td>
</tr>
</tbody>
</table>

Table 3. Effect of fluid inlet temperature

Table 1 shows that the electrical efficiency increases from 10.83% at \( G = 890 \) W/m\(^2\) to 11.01% at \( G = 955 \) W/m\(^2\) due to larger amount of solar irradiance incident on the surface of the PV cells while there is a decrease in thermal and overall efficiencies from 61.79% and 71.16% to 57.59% and 67.12%, respectively. Both the mass flow rate and the fluid inlet temperature were kept constant at 0.018kg/s and 25˚C respectively. The decrease in thermal efficiency is more significant than the increase in electrical efficiency and hence, accounting for a reduction in overall efficiency. The decrease in thermal and overall is mainly due to radiation losses which occur to the ambient.

It can be observed from Table 2 that the electrical efficiency increases considerably from 9.87% at \( \dot{m} = 0.009 \) kg/s to 10.58% at \( \dot{m} = 0.018 \) kg/s while there is only a slight increase in thermal and overall efficiency from 44.08% and 52.62% to 44.23% and 53.39%, respectively. Both the solar radiation and the fluid inlet temperature were kept constant at \( G = 955 \) W/m\(^2\) and 40˚C respectively. The higher the mass flow rate, the quicker the PV cells are cooled down and the larger is the amount of heat that are carried away. Hence, this improves the electrical, thermal and overall efficiencies.

The commercial hybrid PVT solar collector has lower performance at higher fluid inlet temperature as seen in Table 3 which shows that the electrical, thermal and overall efficiency decrease from 11.01, 57.59% and 67.12% to 10.58, 44.23% and 53.39%, respectively as the temperature increases from 25˚C to 40˚C at constant solar radiation, \( G = 955 \) W/m\(^2\) and constant mass flow rate, \( \dot{m} = 0.018 \) kg/s. This is because the PV panel is cooled down more easily and there is minimal radiation loss.

• Temperature coefficients

<table>
<thead>
<tr>
<th>Temperature Coefficient of ( V_{oc} )</th>
<th>-95.2 mV/˚C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Coefficient of ( I_{sc} )</td>
<td>0.003%/˚C</td>
</tr>
<tr>
<td>Temperature Coefficient of ( P_{max} )</td>
<td>-0.29%/˚C</td>
</tr>
</tbody>
</table>

Table 4. Temperature coefficients at \( G = 955 \) W/m\(^2\)
• **Overall heat loss coefficient & Heat removal factor**

The values of \( F_R \) and \( U_L \), given in Table 5, for the commercial PVT module were evaluated using the ASHRAE method. The values of thermal efficiency, \( \eta_{th} \), of the commercial PVT panel at different inlet temperatures were plotted against the values of \( \frac{(T_{fi} - T_a)}{G} \), the reduced temperature, as shown in Figure 1. The thermal efficiency of a flat plate thermal solar collector is usually given by:

\[
\eta_{th} = F_R (\alpha_T) - F_R U_L \left( \frac{T_{fi} - T_a}{G} \right)
\]

The following equation uses the experimental approach to determine the thermal efficiency of the flat plate solar thermal collector:

\[
\eta_{th} = \frac{m C_p (T_{fo} - T_{fi})}{A_e G}
\]

The thermal efficiency could be calculated by measuring the inlet and outlet temperature of the fluid circulating through the thermal collector and the solar irradiance incident on the surface of the PVT panel. The overall efficiency is the sum of the thermal and electrical efficiencies given by:

\[
\eta_o = \eta_{el} + \eta_{th}
\]

![Figure 1. Thermal efficiency (ASHRAE) curve at \( G = 955\text{W/m}^2 \) and \( \dot{m} = 0.018\text{ kg/s} \)](image)

<table>
<thead>
<tr>
<th>Table 5. Overall heat loss coefficient &amp; Heat removal factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill Factor (from manufacturer)</td>
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<tr>
<td>Overall heat loss coefficient, ( U_L )</td>
</tr>
<tr>
<td>Heat removal factor, ( F_R )</td>
</tr>
</tbody>
</table>

**TRNSYS Analysis**

• **Thermal & Electrical Power Supply & Demand in Summer & Winter**

A DHW storage tank is used to store the thermal energy output of the PVT module and the domestic hot water is obtained from the tank according to the need as shown in Figure 2. This is because the thermal energy supply is higher than the demand. The PVT module covers only part of the electricity consumption as shown in Figure 3. The case shown below represents the results of the thermal and electrical energy demand and supply for the summer conditions in Mauritius.
Figure 2. Hourly thermal power supply & demand in summer in Mauritius.

Figure 3. Hourly electrical power supply & demand in summer in Mauritius.

Reduction in Carbon dioxide Emissions & Financial Analysis

Table 6. Carbon dioxide emissions reduction & financial analysis

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity basic rate (Rs./kWh)</td>
<td>4.88</td>
</tr>
<tr>
<td>Electricity generated by PVT annually (kWh)</td>
<td>1353.82</td>
</tr>
<tr>
<td>Annual electricity savings on bills (Rs.)</td>
<td>6606.64</td>
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<tr>
<td>Carbon dioxide emission factor (kg/kWh)</td>
<td>0.527</td>
</tr>
<tr>
<td>Annual reduction in CO₂ emission (kgCO₂)</td>
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<tr>
<td>Inflation rate (%)</td>
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<td>Project life (yr)</td>
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<tr>
<td>Debt interest rate (%)</td>
<td>5.00</td>
</tr>
<tr>
<td>Debt term (yr)</td>
<td>10</td>
</tr>
<tr>
<td>Power System Cost (Rs.)</td>
<td>50,000</td>
</tr>
<tr>
<td>Total investment cost (Rs.)</td>
<td>52,500.00</td>
</tr>
<tr>
<td>Payback Period (years)</td>
<td>8</td>
</tr>
</tbody>
</table>

(Rs.) – Mauritian Rupees
There is no feed-in-tariff (FITs) and export tariff being provided at present in Mauritius. There is also no incentive as such being offered for the amount of reduced carbon dioxide emissions. So the benefit of integrating the PVT system into the residential building in Mauritius is restricted to the savings made on electricity bills.

The annual reduction in carbon dioxide emission in Table 6 was obtained by the product of the annual electricity generated by the PVT panel and the carbon dioxide emission factor which was assumed to be 0.527 kg/kWh, as that estimated in the UK.

A total of 4 units of PVT panel, each with an estimated installation cost of around Rs. 12,500, were to fit the estimated available roof area of 5 m² in the residential setting in Mauritius. The installation cost includes all aspects from the PVT panel to the AC inverter and labour cost. The payback period for the installation of the PVT system in the residential building in Mauritius was found to be no longer than 8 years with a project life of 10 years.

Conclusion
The combination of photovoltaic and thermal solar collector in one single device called the hybrid photovoltaic-thermal solar collector not only enhances the power density but also reduces the cost of operating the system as well as the space utilisation when compared to side-by-side PV modules and solar thermal. The thermal energy supplied by the PVT collector is greater than the thermal load demand and the electrical energy supplied covers only part of the electrical load demand.

The feasibility study about the integration of the PVT system in Mauritius gives a good insight about the time needed to recover the cost of installation of the PVT module while also indicating how much reductions in carbon dioxide emission could be achieved. It was demonstrated that the payback period would be no more than 8 years and that there would be an annual reduction of about 0.713 tonnes of carbon dioxide emission. Therefore, this concludes that there is good potential for hybrid photovoltaic-thermal (PVT) solar collectors in Mauritius.

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How Sustainable is Tourism Architecture in Uganda?

Goodman Conrad Kazoora

Master of Architecture (Prof), Faculty of the Built Environment, Uganda Martyrs University, Goodman.Kazoora@unhabitats.org

Abstract

Among the most remarkable socioeconomic phenomena of the post-World War II era has been the expansion of the global tourism industry (Weaver, 2006). A phenomenon with far reaching effects like this needs to be carefully controlled and planned so as not to compromise the chances for the future generations to enjoy this resource, therefore the issue of tourism sustainability, as a result, is unveiled. The concept of sustainable tourism remains vague in Uganda as the country has seen an increase in resorts, hotels and lodges especially in most of Uganda’s ecologically vulnerable areas National Parks. Architecture can be the first means to link the global dimension of this phenomenon of sustainable tourism to its local implications (Deda, 2001). The aim of this paper is to critically analysing the extent to which sustainability related considerations have been pursued in the built environments for Uganda’s national parks.

Keywords: Sustainable Tourism, Tourism Architecture,

1. Introduction

According to Weaver (2006), among the most remarkable socioeconomic phenomena of the post World War II era has been the expansion of the global tourism industry. Major changes in the second half of the twentieth century, like increased international travel, has led to the massive growth of tourism globally (Williams, 1999). It is a rapidly growing sector with broad economic, social, cultural and environmental consequences that is likely to dominate the world scene for many years to come (Ozgen, 2003). Weaver (2006) claims that with the tourism sector continually being reinforced by growth in visitation numbers, it is reasonable to contend that every place on earth can now be considered a tourist destination. Intensifying tourism activity is continuing to affect more and more places and there can no longer be any doubt as to the potential of this sector to affect fundamental economic, social-cultural and environmental change (Morandotti, 2006). A phenomenon with far reaching effects like this needs to be carefully controlled and planned so as not to compromise the chances for the future generations to enjoy this resource, therefore the issue of tourism sustainability, as a result, is unveiled (Weaver 2006). A term that has gained its popularity due to the increased environmental awareness, Sustainable Tourism was realised by scholars and researchers as early as the 1960s (Ozgen 2003). To some it is merely the application of the sustainable development idea to the sector of tourism (Weaver 2006). To others like Khaksar (2011), it is the conservation of the environment and its natural resources, realising and appropriately using them to achieve sustainable built environments that promote tourism. As tourist destinations continue being repackaged for mass consumption (Cooper, 2007), there is a need to start realising that the environment is an asset to tourism and not a public good that is subject to demand and over exploitation (Ozgen, 2003), and start protecting this asset. Keeton (2012) says, ‘If a company cannot be bothered to offer sustainable holidays, by definition it must have a limited lifespan. If what a company is offering is destroying the very place it relies upon, then the product is finite’. This is where Sustainable Tourism strikes home.
The concept of sustainable tourism remains vague in Uganda as the country has seen an increase in resorts, hotels and lodges especially in most of Uganda’s ecologically vulnerable especially National Parks. Uganda’s tourism activity is mainly centred in national parks. These protected areas are the very place upon which Uganda’s tourism relies and can be considered sensitive assets to the tourism industry of Uganda. The key question that this paper intends to answer is how much are Ugandan tourism operators willing to protect their environment through sustainable built environments.

There are many examples of sustainable tourism resorts, or what are claimed to be sustainable tourism resorts, throughout the country. The truth is that true sustainable tourism resorts are very few and far between (Mahravan, 2012).

1.1. Sustainable Architecture and its relation to tourism

Architecture can be the first means to link the global dimension of this phenomenon of sustainable tourism to its local implications (Deda, 2001). Therefore architecture can play a significant role in making the concept of sustainable tourism clear. Khaksar (2011) says that architecture has the talent of defining spaces and therefore has a powerful influence on the human behavior and understanding and this is exactly what is always taken into account in sustainability, maximising economic benefit and preserving the ecosystem.

Sustainable architecture has not only become a selling point for many tourism resorts but also it is highly demanded in the tourism market especially within the tropics. Bromberek (2009) suggests that developers of tourism destinations today especially in tropical regions have to meet the demand to accommodate growing flows of people who arrive there with quite specific expectations like sustainable architecture.

Higgins (2006) goes further to suggest that we need to look beyond the fancy words and actually put these sustainability principles in practice.

Contrary to writers like Sharpley (2009) and Arnold (2012) who claim that sustainable tourism is a superficial term that cannot be measured, Bromberek (2009) suggests that the first basic point of measurement of sustainable tourism can be through its architecture. Bromberek (2009) says that sustainability objectives, relevant to the built environment, can be both tangible and measurable. Apart from others, which are not less important, in the technological area they are: Conservative management of the natural environment; Minimising non-renewable resource consumption; Reducing embodied energy and total resource usage; Reducing energy use; Minimising external pollution and environmental damage; Eliminating or minimising the use of toxins; and minimising internal pollution and damage to health.

All these objectives put together can be expressed as the ultimate (technological) goal of sustainable architecture to restrict the impact that the buildings make on their surroundings to an unavoidable minimum. This is why ‘sustainable architecture’ can be referred to as ‘low-impact architecture’. It is through this ‘low-impact architecture that tourism can pursue sustainability as Deda (2011) suggests.

2. The study area and selection criteria

A recent survey by the Uganda Wildlife Authority (2010) revealed that Queen Elizabeth National Park is the most visited protected area in Uganda partly because it’s one of the largest. The map shown in Figure 1 is Queen Elizabeth National Park. According to the Uganda Tourism Board, Queen Elizabeth National Park accommodates over 16 safari lodges of which 7 of them are within the park boundaries. That is the highest number of safari lodges in a protected area than any other national park in Uganda. On the surface, it is the most
likely protected area greatly affected by increased tourism developments and increased tourist visits for the last 10 years. This makes it a good study area.

Figure 1: Queen Elizabeth National Park

The selection of the specific tourist destinations looked out for tourist destinations that are not over ten years old because the chances that sustainability measures were pursued in their planning are less due to the little popularity of the subject in the past. The operators of the tourist destination had to claim that their destination was designed on sustainability principles and this information can be obtained from tourism brochures and internet websites of these particular destinations. Lastly, the site needed to be one that is within the park boundaries or at the periphery of the park boundaries where its impact directly affects the protected area. The above criteria left six clear areas of study and these were: Queen Elizabeth Bush Lodge, Ihamba Lakeside Safari Lodge, Kyambura Lodge, Ishasha Wilderness Camp, Kingfisher Lodge and Kazinga View Resort.

2.1. Selection of Rating Tool

Selection of the appropriate sustainability-rating tool was key to making this study valid. The selected tool was based on the BREEAM model that looks at 6 different issues that is, energy efficiency, water efficiency, site planning and management, materials and resources, indoor environment quality and innovation. The tool also had to be from a country with an established sustainable building-rating scheme and recognised by the World Green Building Council.

The tool also had to come from a country with a comparable climate to Uganda. That is, the country whose rating tool shall be used had to be closer to the equator than all the options available. For this paper, the Green Building Index of Malaysia was adopted.
3. Results

Figure 2: Results as assessed with the Green Building Index

Figure 3: Ranking in the Green Building Index

These results answer question that was stated earlier in this paper that: **How sustainable is tourism architecture in Uganda?** The architecture studied in this paper is not as sustainable as they claim it is. The graphs above present a picture of how the studied sites rank against each other and also how they rank in the Green Building Index standards. None of the sites made it to certification level. This can only mean that the concept of sustainability, sustainable tourism and sustainable architecture are not fully understood and in that regard, the architecture is not as sustainable as it should be. These results reveal a lot especially for the sites that made a lot of claims that they are sustainable. This situation is the exact situation Glatter (2006) talks about. It is all ‘Greenwash’. He says, “Greenwash is when somebody says that, 'Oh, we have the greenest building in town,' and they do not have the metrics to show that they've done something." This research just confirmed that tourism destinations in Queen Elizabeth National park are all just ‘greenwash’ sites. They claim they are eco, green or sustainable and yet they do not have the metrics to show they are sustainable.
3.1. Comparison to online reviews

Table 1: Comparison to online reviews

<table>
<thead>
<tr>
<th>Study Area</th>
<th>TripAdvisor.com traveller rankings</th>
<th>Sustainability score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyambura Lodge</td>
<td>#3</td>
<td>45</td>
</tr>
<tr>
<td>Queen Elizabeth Bush Lodge</td>
<td>#4</td>
<td>37</td>
</tr>
<tr>
<td>Ishasha Wilderness Camp</td>
<td>#2</td>
<td>34</td>
</tr>
<tr>
<td>Ihamba Lakeside Safari</td>
<td>#8</td>
<td>16</td>
</tr>
<tr>
<td>Kingfisher Lodge</td>
<td>#9</td>
<td>9</td>
</tr>
<tr>
<td>Kazinga View Resort</td>
<td>not reviewed</td>
<td>5</td>
</tr>
</tbody>
</table>

The sustainability scores obtained from this research were juxtaposed to the rankings from a renowned online tourism review website (tripadvisor.com). There seems to be a direct correlation between sites that scored highly in this research and being highly ranked on tourism websites. This means that the sites that scored high sustainability points in this thesis are not only ranked highly by reviewers but are also more likely to get more clientele than the less sustainable sites. Tourists are more likely to visit sites that have low building footprint, built from local materials, energy efficient and all the qualities of sustainable architecture than sites that do not. It means that, tourism architecture today has no choice but to be sustainable otherwise it will fail both as a business and as destination.

4. Conclusions

This paper brings forward the mysteries and lack of consensus of the true definitions of the terms sustainability, sustainable tourism and sustainable architecture. This lack of consensus seems to have clouded the true objectives of these concepts and many writers like Sharpley (2009) have questioned their practicality in today’s world. However, despite the criticism that sustainable tourism has met over the years, Keeton (2012) claims, that a concept like this with a philosophy that not only reduces the negative effects of our tourism, but also increases the positive ones for both client and company alike, it’s hard to argue with the logic behind it. One can be sure that sustainable tourism is no passing fad.

This paper has revealed that many tourism destinations are self-proclaiming themselves to be sustainable with all sorts of catchy phrases like ‘eco’ or ‘green’ and that may not be the case. Furthermore this research exposes Uganda’s building and planning authorities and professionals’ bodies for failing to play their part. Building in the most sensitive sites like National Parks needs the most attention to detail and scrutiny by these authorities. But this may not be the case. As a result, many unsustainable buildings get approved and built without question. Some of the most unsustainable developments that occur in these sensitive sites become benchmarks for the future projects and in the near future the national park will exist no more. Until this system is fixed, the National Park will continue to lose its value.

Lastly, this research shows the relationship between sustainable architecture and the tourism market today. The market today is more biased to tourism destinations that are actually sustainable. Tourism developments of the future have no choice but to be sustainable otherwise they will fail both as businesses and as destinations. Why this is not a sign to Uganda’s tourism developers to change their ways is still a mystery.
5. References


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Multi-objective assessment of ventilation strategies in a case-study dwelling in the Delhi climate

Caiyu Chen¹, Payel Das² and Emily Nix²

1 MSc Environmental Design and Engineering, UCL, UK, Email: caiyu.chen@ucl.ac.uk.
2 Bartlett School of Graduate Studies, UCL, Central House, 14 Upper Woburn Place, London, UK

Abstract
In this study, a typical flat constructed by the Delhi Development Authority (DDA) was modelled in EnergyPlus. Different ventilation strategies including architectural revision and mechanical interventions were applied to this model. Considering potential health and energy impacts of ventilation systems, PM2.5 concentration, overheating time and energy consumption were chosen to assess the strategies. ANOVA tests and multi-objective assessment were carried out to estimate the impact of different interventions and to determine the optimal healthy and energy-saving strategy. Results showed that all interventions including the enlarging of windows, the movement of kitchen, exhaust fan, air conditioning and zone control significantly affected the contaminant concentration while the reduction of overheating was much more significant with air conditioning. Overall, the multi-objective assessment shows that the ventilation strategy of the exhaust only system is the most reasonable choice if the relative weight is equal.

Keywords: Ventilation, Multi-objective, Delhi

1. Introduction

1.1 Impact of ventilation in the indoor environment

Many researches demonstrate that the high risk of allergies, SBS symptoms and respiratory infections is associated with a low ventilation rate in buildings (Sundell et al., 2011). Besides, Milton et al. (Milton et al., 2000) find that by increasing the outside air ventilation rate from 12 l/s per person to 24 l/s per person, the short-term sick leave rates would be reduced by almost 35%.
On the other hand, except from outdoor air pollutants, indoor particulate pollutants are also crucial to people’s health. According to the study conducted by US EPA particle total exposure assessment methodology, cooking becomes the second largest indoor source of particles (Wallace, 1996) in modern dwellings. The concentration of particles in the near-field of the kitchen is detected nearly three times higher than that in the far-field (Lai and Ho, 2008). Therefore, the window openings and layout of the kitchen should be well planned to prevent cross pollution with other living space.

1.2 Multi-objective assessment of ventilation strategies
In most cases, the strategy cannot satisfy all the respects at the same time. Thus, there is a trade-off in the assessment of ventilation strategies. The method of multi-objective assessment and optimization gives a clue to solve the problem. It has been applied in various fields of science, including economics, logistics and engineering where optimal decisions need to be made between several conflicting objectives such as health impacts, energy consumption and cost. In terms of ventilation strategies, researchers take advantages of multi-objective optimization to minimize the cost, or energy consumption while maximize the health and comfort level when determining ventilation rates in dwellings (Das et al., 2012, Das et al., 2013, Rackes and Waring, 2014).

2. Methodology

2.1. The case study dwelling
The case study is a flat model of the DDA archetype, located in the central Delhi. The simulation runs with a typical meteorological year weather file for Delhi. The weather file contains annual hourly values of variables from historical weather records and represents typical conditions rather than extreme periods. Specific data for New Delhi is developed according to the Indian Society of Heating, Refrigerating and Air-Conditioning Engineers (New Delhi Wearther File n.d.)

The flat has a total floor area of 82 m² and a small balcony with shading next to the living and main bedrooms. It consists of nine separate rooms with a landing space. The plan view of the flat can be seen from Figure 1.

2.2 The base and proposed cases
The flat with natural ventilation is regarded as the base case. In this case, windows, balcony doors and external doors are set to open when the internal air temperature is beyond 28 ºC.

- Proposed Case 1 (PC1) -- double size windows: The external windows are expanded to the double of the previous size.
- Proposed Case 2 (PC2) – double size kitchen window only: In this case only the kitchen window is two times as large as that of the base case.
• Proposed Case 3 (PC3) – replace kitchen with Store 1 (northeast): PC3 exchanges the position of store 1 and kitchen.
• Proposed Case 4 (PC4) - replace kitchen with landing space (southwest): In proposed case 4, the kitchen exchanges the place with the landing space.
• Proposed case 5 (PC5) – Exhaust only systems: An exhaust fan is placed in the kitchen to provide better ventilation.
• Proposed Case 6 (PC6) - Air conditioning systems: In this case, air conditioning is used to set to trigger at a zonal air temperature of 30 ºC. Additionally, ceiling fans are used in the living room, kitchen and bedrooms at 400W. According to each zone’s function and occupancy pattern, diverse schedules are allocated to main zones.
• Proposed Case 7 (PC7) - Zone control systems: In proposed case 7, the living room, bedrooms and dining room are designed with an air conditioner while the kitchen is equipped only with exhaust fans.

2.3 ANOVA Test

Firstly, an F test is carried out to illustrate whether the proposed strategies indeed have considerable impact on the performance of the dwelling, which means the occurrence of result is not by accident. More precisely, the performance refers to the hourly PM$_{2.5}$ concentration level and indoor temperature. Then, a one-tailed Z-test is made to see whether PM$_{2.5}$ level and overheating are significantly reduced with proposed strategies.

2.4 Multi-objective assessment

In this study, a multi-objective assessment based on the weighted-sum multi-objective methodology (Das et al., 2013) is applied. To simplify the calculation, initially assume all the performance criteria weights are the same. Since three factors are taken into consideration in this study (PM$_{2.5}$, temperature and energy), the weight value is set at 1/3 equally. Therefore, in this study, the single objective function can be as follows:

\[
G(x) = \frac{P(x)}{3P_{\text{max}}} + \frac{T(x)}{3T_{\text{max}}} + \frac{E(x)}{3E_{\text{max}}}
\]

Where,  
P: Mean PM$_{2.5}$ concentration level in a year
T: Overheating time
E: Energy consumed annually
x: Different cases, x=0,1,2,3,4,5  x=0 refers to the base case.

3. Result and Discussion

3.1 ANOVA test
The z test result of PM$_{2.5}$ concentration level and F test result of indoor mean temperature are shown in Figure 2 and Table 1. The critical z value is 1.64 and critical F value is 3.84. In most cases, the z value is much less than -1.64. So, the statistical analysis indicates the PM$_{2.5}$ concentration is very sensitive to all the proposed strategies. In Table 1, Figures with red color exceed the critical F value, which means the proposed case has significant impact on the internal temperature.

3.2 Multi-objective optimization

<table>
<thead>
<tr>
<th>PC1 (double size window)</th>
<th>PC2 (double size kitchen window)</th>
<th>PC3 (kitchen and Store1 exchange)</th>
<th>PC4 (kitchen and Landing exchange)</th>
<th>PC5 (exhaust only)</th>
<th>PC6 (air conditioning)</th>
<th>PC7 (zone control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC (natural ventilation)</td>
<td>149.71</td>
<td>2864</td>
<td>2427.25</td>
<td>0.74</td>
<td>156.66</td>
<td>156.27</td>
</tr>
<tr>
<td>PC1</td>
<td>133.95</td>
<td>2588</td>
<td>2427.25</td>
<td>0.67</td>
<td>129.67</td>
<td>129.67</td>
</tr>
<tr>
<td>PC2</td>
<td>136.21</td>
<td>2782</td>
<td>2427.25</td>
<td>0.70</td>
<td>156.44</td>
<td>156.44</td>
</tr>
<tr>
<td>PC3</td>
<td>156.44</td>
<td>2809</td>
<td>2427.25</td>
<td>0.75</td>
<td>194.6</td>
<td>194.6</td>
</tr>
<tr>
<td>PC4</td>
<td>129.67</td>
<td>2791</td>
<td>2427.25</td>
<td>0.69</td>
<td>156.66</td>
<td>156.66</td>
</tr>
<tr>
<td>PC5</td>
<td>102.27</td>
<td>2803</td>
<td>2533.27</td>
<td>0.64</td>
<td>102.27</td>
<td>102.27</td>
</tr>
<tr>
<td>PC6</td>
<td>87.69</td>
<td>2669</td>
<td>8165.12</td>
<td>0.79</td>
<td>87.69</td>
<td>87.69</td>
</tr>
</tbody>
</table>

Table 2 G(x) value
In terms of the multi-objective assessment, the kitchen, bedrooms and the dining room are observed for analysis. The mean PM$_{2.5}$ concentration level and annual overheating hours are calculated for occupied hours in each room. As presented in Table 2, proposed case 5 has the minimum G value. Apparently, the kitchen has better performance in terms of both the pollutant level and overheating time, if it is positioned in the southwest corner of the dwelling (PC4) rather than the northeast corner (PC3). Overall, the multi-objective assessment shows the flat with the exhaust fan is the best.

However, this conclusion is based on equal weight approach as discussed in the methodology chapter. Sometimes, people care more about the health and comfort level of a dwelling. This time, let’s assume the relative weights are 2/5, 2/5, 1/5 for PM$_{2.5}$, overheating and energy respectively. The result of the G value is presented in Figure 3.

![Figure 3. G value with unequal weights (2/5, 2/5, 1/5)](image)

In this case, air conditioning system (PC6) turns out to be the most reasonable strategy for the dwelling. Therefore, according to different requirement or preference, the suggestion for the dwelling is quite different with multi-objective assessment. Moreover, Kusiak and Li (Kusiak and Li, 2009) claims that an optimal operation schedule for mechanical ventilation system might significantly reduce the energy consumption, thereby changing the conclusion of the multi-objective assessment.

4 Conclusion

Ventilation plays a crucial role in providing a comfortable and healthy indoor environment for occupants. The aim of this study is to find out the best ventilation strategy for dwellings in Delhi using multi-objective assessment. Building performance is simulated by software EnergyPlus. PM$_{2.5}$ concentration level, overheating time and energy consumption are three main factors to represent the performance of the dwelling.

For PM$_{2.5}$ concentration, as all the external windows are enlarged, the level in every room declines. In terms of Delhi, the results demonstrate the southwest corner of the dwelling is more reasonable for the kitchen rather than the northeast corner. For overheating problem, all the architectural revisions show no substantial difference on the amount of annual overheating hours. Nonetheless, for air conditioning system and zone control system, ANOVA test indicates the temperature in the bedrooms is not decreased to a statistically
significant level. The energy consumption is equal to all the natural ventilation cases. The annual energy consumed by air conditioning systems is almost 4 times larger than that of natural ventilation systems.

The multi-objective assessment shows that the exhaust only system is the best one if the PM$_{2.5}$ level, overheating and energy consumption are equally considered. However, according to distinct requirement or preference, applied with different relative weights the suggestion for the dwelling is quite different. As usual, there are several limitations in this study. For example, there is no combination between proposed cases. Each proposed case is discussed independently. Therefore, further study could apply multi-objective assessment with proposed case combination, such as double size window and exhaust only system integrating.

Reference


New Delhi Wearther File n.d.: Indian society of heating refrigerating and air-conditioning engineers.


