IMPLICATIONS OF CLIMATE CHANGE AND OCCUPANT BEHAVIOUR ON FUTURE ENERGY DEMAND IN A ZERO CARBON HOUSE

Halla Huws and Ljubomir Jankovic
Birmingham School of Architecture
Birmingham Institute of Art and Design, Birmingham City University
The Parkside Building, 5 Cardigan Street, Birmingham B4 7BD
United Kingdom

ABSTRACT

The Birmingham Zero Carbon House is a retrofitted Victorian house that has achieved carbon negative performance. Future predictions of temperatures are showing an increase in Cooling Degree Days (CCD), even under a low carbon emissions scenario. This paper aims to investigate the human behaviour effect on maintaining indoor thermal comfort in future weather, in various models of cooling in the Zero Carbon House. As a result, evaluating the implications of climate change on energy consumption, and the extent to which the occupant behaviour can minimise the growing demand in energy are investigated.

INTRODUCTION

Context & aim

The Birmingham Zero Carbon House is a retrofitted Victorian house that has achieved carbon negative performance. The house has been extensively simulated in parallel with detailed instrumental monitoring (Jankovic and Huws, 2012).

Instrumental monitoring of the house was carried out to study the real life performance, collecting data of energy production and consumption as well as indoor thermal conditions. A dynamic simulation model of the house was developed and the calibration of the model was carried out using data from monitoring.

The calibrated simulation model was subsequently used to study the building performance in different future climates, using probabilistic future weather data for 2030, 2050 and 2080 in a medium carbon emissions scenario.

The aim of this paper is to investigate the ability of human behaviour to achieve thermal comfort in the future, and the relationship between human behaviour, such as adjusting clothing and activity, and summer cooling energy load resultant from free cooling and air-conditiong. The study uses a simulation model of the Zero Carbon House, with current and future weather files for Birmingham.

Although it might be obvious that free cooling and lower clothing and metabolism values will lower discomfort, this is not necessarily recognized in a building that is going through climate change over a long period of time. Hence our analysis shows that such measures need to be considered gradually. We will be highlighting the fact that occupants are capable of achieving thermal comfort without mechanical intervention to some extent, and demonstrating the importance of taking that into cosideration.

Climate change and energy

The UK Government described Climate Change as the "Greatest long-term challenge" facing the world today (HM, 2006). The UK climate change predictions suggest an average warming per decade, varying between 0.1 °C to 0.3 °C for a low carbon emissions scenario and 0.3 °C to 0.5 °C for a high carbon emissions scenario (Hulme et al., 2002).

Most of the European buildings are currently naturally ventilated, but energy consumption related to cooling has been rising recently, in particular in southern Europe as well as in the UK (Perez-Lombard et al., 2008).

Studies have predicted that the increase of temperatures in South England might result in up to 29% of homes having air-conditioning by 2050 under a low emissions scenario, and 42% in a high emissions scenario (Boardman et al., 2005). The increase of air conditioning requirement will result in a new type of energy demand in the UK, which might hinder reaching future carbon reduction targets (Chan, 2011).

Thermal comfort

Thermal comfort is defined in the IS0 7730 standard as "That condition of mind which expresses satisfaction with the thermal environment". Being an important aspect in building design, thermal comfort needs to be converted into physical parameters (ISO, 1984).

Fanger's seminal research resulted in an equation to predict the thermal sensation of occupants. This equation is based on thermoregulation and heat exchange and consists of six variables. Four of these variables are environmental: air temperature, mean radiant temperature, relative humidity and air velocity. The other two variables are personal: clothing and metabolic rate (Fanger, 1970).

Fanger subsequently developed the concept of the thermal comfort index PMV (Predicted Mean Vote) by relating his equation to a seven-point sensation scale. He also developed a related index, called the Predicted Percentage Dissatisfied (PPD). This index is a function of PMV, and it predicts the percentage of people who are likely to be dissatisfied within a given thermal environment (Fanger, 1970).

A PMV model is used in standards to recommend acceptable thermal comfort conditions. The recommendations made by ASHRAE Standard 55 require that at least 90% of occupants feel thermally satisfied, or a PPD of 10% or less (ASHRAE, 2003).

Field studies have shown a wider comfort conditions range than given by Fanger's equation, De Dear explained that firstly, Fanger's equation ignores climatic adaptation, which suggests that physiological experiences and human expectations will both have an effect on what occupants will consider comfortable; secondly, although the equation is valid, it does not take into account the flexibility people have in their environment allowing them to make changes and adjust by changing the environmental or personal variables of the equation, using fans, shading, clothes or adjusting activity level (De Dear, 1994).

Adaptive thermal comfort

The adaptive approach to thermal comfort comes from the natural tendency of people to adapt to changing conditions in their environment. The adaptive principle states: if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort.

Based on that, the thermal comfort vote is also linked to the actions occupants can resolve to, which links comfort to the context they are in, having the climate itself as the prime contextual variable.

People can adjust the conditions that they find comfortable by changing their clothes, their activity levels and body postures, increasing or decreasing the body surface exposed to air. Therefore, these are considered as adaptive opportunities, although they have no effect on the surrounding conditions.

A new Technical Memorandum addressing adaptive thermal comfort is being developed by CIBSE, in order to address the limited data for outdoor mean temperatures greater then 25 °C. Research shows that when outdoor temperatures exceeds 25 °C then the upper limit for indoor operative temperature for healthy adults would increase to 31 ^{o}C (Porritt et al., 2012). Therefore, thermal comfort thresholds will rise with the rising temperatures, taking into account the human adaptation.

Buildings require robust solutions based on physical changes to reduce the risk of overheating. In addition to that, behavioural changes need to be taken into consideration, such as the ability to adjust clothing and change of activity. The latter could be applied through zoning, and moving the activities according to the season.

This study investigates: 1) The expected increase in cooling energy to maintain indoor thermal comfort in the current and future climate; 2) The reduction in cooling energy demand when taking behaviour modification into account; 3) The extent to which the human behaviour contributes towards reducing energy demand and maintaining the zero carbon performance.

METHODOLOGY

Instrumental monitoring

An extensive data monitoring system was installed in the case study site, which allows systematic recording of detailed information of building and system conditions, such as room and system temperatures, weather parameters, energy flows etc. The information gathered allows an evaluation of the thermal conditions in the building for different seasons and conditions of occupancy and use. Additionally, the energy requirements and energy savings from the zero carbon technologies are obtained, and the carbon emissions from the house are calculated.

Simulation Model

The IES-VE Software was chosen due to its accuracy and versatility as well as the availability of the software license at the University. Furthermore, it is approved for use in compliance checking according to the Part L2 of the Building Regulations for England and Wales and consequently it is commonly used software in the UK by engineering consultants (Murray et al., 2011, Kim et al., 2011).

Calibration

Calibration of the model was carried out before investigating the building behaviour under future weather, in order to minimise the performance gap that regularly occurs between the simulation model and the actual building.

This included both energy and temperature calibration, and resulted in a model with a root mean squared temperature error of less than 0.95°C, and a relative error between simulated and actual energy consumption of 0.06% (Jankovic and Huws, 2012).

Future overheating

The UKCP09 are currently the most advanced climate scenarios in the world. They are based on advanced climate modelling, past observations, IPCC (Intergovernmental Panel on Climate Change) emissions scenarios and expert judgement (UKCIP, 2010).

The UKCP09 has three scenarios; high emissions, medium emissions and low emissions to represent different possible future states (UKCIP, 2010). UKCP09 also attempts to quantify the uncertainties by using probabilistic projections where data are structured in 5 Cumulative Distribution Function

(CDF) probability levels of (10%, 33%, 50%, 66% and 90%) (UKCP09, 2010).

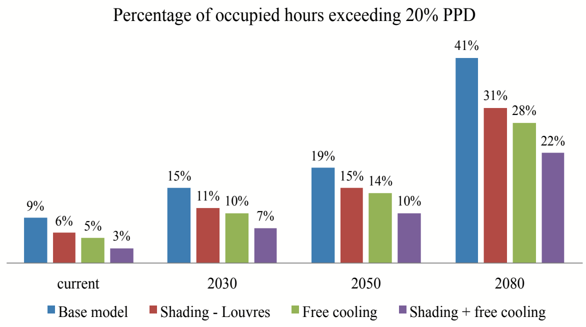

Figure 1 Summer Overheating reduction methods

Using the UKCP09 weather data to predict future performance of the Zero Carbon House indicated the need for adaptation methods to maintain the zero carbon performance in the future, as PPD levels greater than 20% are expected to account for 41% of occupied hours by 2080. To reduce discomfort from overheating, simple mitigation methods were applied, such as external shading and free cooling as shown in Figure 1. Nevertheless, discomfort was still occurring which would suggest a need for further mechanical cooling accompanied by higher energy requirements.

At this point it is useful to note that there is a difference between designing a building for a future climate year in which ASHRAE:90.2 or other standards suggest mandatory free cooling, and designing the building for the current climate and letting it go through climate change (ASHRAE, 2007). In the latter case, the building will not necessarily have dynamic simulations carried out on it routinely, informing the building owner of the need to introduce free cooling and equipment required to achieve it, as climate change starts to influence thermal comfort. In this case human behaviour could play a major role in reducing discomfort until more extreme measures are required.

Investigating thermal comfort

In the IES software the default comfort settings are 0.69 clo for clothing and 0.9 met for activity (1 met = 58 W/m^2; 1 clo = 0.155 m^{2}K/W), meaning that people are expected to be wearing the same type of clothes across all seasons and living at the same activity level throughout the year.

The comfort settings in this particular software package are adjustable post-simulation to analyse their effect on the PMV and PPD. However, they can only be changed into one fixed value for the whole year, not taking into consideration daily or seasonal changes, which is not realistic. People not only alter their level of clothing during seasons, but also on a daily basis through short-term adjustment of clothing, such as the addition or the removal of a whole garment. Therefore, even when adjusting those values they will not be a true representation.

Additionally, our experience of common practice of IES users is that nobody makes any adjustments to the set values of met and clo. In this paper we demonstrate how adjusting these values on an hourly basis could lead to better designs that do not use mechanical cooling unnecessarily, as opposed to using the IES results on the face value.

The calibrated simulation model using the current climate weather file and fixed personal parameters throughout the year indicates high levels of discomfort: Predicted Percentage of Dissatisfied (PPD) was 17% in winter and 18.6% in summer. However, a detailed thermal comfort study of the zero carbon house carried out by Jankovic (2012) found that PPD was 6.87% in winter and 5.17% in summer, hence quite close to thermal neutrality as defined in ASHRAE 55-2004 of PPD=5% for predicted mean vote of PMV=0.

The environmental variables within the thermal comfort equation were obtained from the monitoring and modelling stages. This indicated that occupants had managed to adapt to their environment by making changes in the personal comfort variables. Therefore, the predicted PMV and PPD by IES software are not realistic, due to the yearly fixed values of personal variables.

Clothing adjustment

To evaluate the effect of clothing adjustment on the energy demand in summer conditions in current and future weather, the IES model was used. The simulation was based on four different Birmingham weather files: current, 2030, 2050 & 2080, all in a high emissions scenario of 50 percentile.

An initial test looked at the relationship between the clothing levels and the predicted percentage dissatisfied (PPD), using the current weather file. The simulation showed that on the 21st of July (peak summer day) the average PPD was 32%, based on default values of 0.69 clo and 1.5 met. Changing the clothing resistance value to 0.2 clo (light summer clothing) resulted in a reduced PPD with an average of 12%. The analysis of the PMV showed that the majority of votes before the change corresponded to the slightly warm perception, and with reducing the clothing, they mostly corresponded to the slightly cold perception.

This issue is very similar to what would happen in a whole year simulation, as the software does not give a flexibility of daily or seasonal clothing adjustment.

In order to test the comfort conditions with more flexibility, and more realistic behaviour of clothing adjustment, this part of the study was analysed manually using standard spreadsheet software, with all the environmental variables imported from the simulation results. As the simulation software analyses thermal comfort in a post-processing mode, during the review of results after the simulation has been completed, the manual post-processing method in a spreadsheet is justified.

Although we would normally make annual comparisons of simulation results on an hourly basis, the analysis in this paper is concerned with overheating only, and thus we take only summer months into account. We note that the peak week is not the best representation of future climate years as, for instance, the cooling energy for peak weeks would be lower in 2030 and 2050 than in the current climate, even though the overall summer cooling energy would be higher. Therefore the comparisons have been made for summer months in each climate year, for the period between 1st June and 30th September. The overall summer period results are shown in Table 2 and Table 3.

The models were initially simulated as 'free-running', without any space conditioning, relying on natural ventilation for cooling. Subsequently, the air temperature, mean radiant temperature, relative humidity, and air velocity, were input into a spreadsheet, along with the default values used in IES for clothing and metabolic rate to calculate the initial resultant PMV and PPD.

The calculated PMV represents how people would feel within the space. According to this value clothing could be increased or decreased, aiming to achieve a PMV closer to zero (PPD between 5% - 10%).

Table 1
Clothing adjustment in relation to PMV

PMV VALUE	ADJUSTED INSULATION (CLO)	CLOTHING DESCRIPTION
PMV < -1 (Cold)	1.25	Underwear + long sleeve shirt, trousers, jacket, socks, shoes
-1< PMV < 0 (slightly cold)	1	Underwear + shirt, jumper, trousers, socks, shoes
PMV = 0 (Neutral)	0.69 (Model value)	Underwear + shirt, trousers, socks, shoes
1 > PMV > 0 (slightly warm)	0.5	Underwear + shirt (short sleeves), lightweight trousers, light socks, shoes
PMV > 1 (warm)	0.25	Underwear + T-shirt, shorts, sandals

The clothing insulation level was adjusted in the spreadsheat, with values of (1.25, 1, 0.69, 0.5, 0.25), using an 'IF function' related to the initial value of PMV, as shown in Table 1. The fixed value of clothing insulation used in the model (0.69) was not changed if the PMV rate was zero, indicating its suitability.

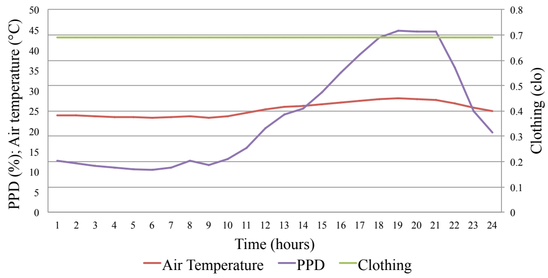

Figure 2 PPD (21st July/ current weather) with fixed clothing

The adjusted clothing insulation values were then used to recalculate the PMV and PPD, to test the effect on improving comfort levels, as shown in Figure 2 and Figure 3.

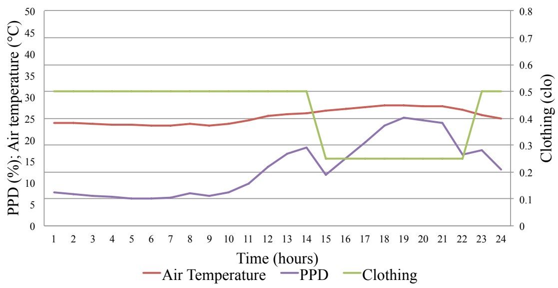

Figure 3 PPD (21st July/Current weather) with flexible clothing

The simulation results in the current and future weather indicated a high rate of dissatisfaction. Therefore, free cooling was suggested as a measure for improving thermal comfort, due to the availability of a mechanical ventilation system. Free cooling was applied when indoor temperature exceeded 23 °C and was higher than outdoor temperature. The energy consumption related to free cooling was calculated by multiplying the number of free cooling hours by the additional free cooling flow capacity and the specific fan power.

However, free cooling was not sufficient to achieve low PPD rates. That was due to the high outdoor temperatures, which suggests a requirement for additional cooling systems to achieve optimum conditions, as shown in Table 3.

Air conditioning was then applied to the model with a cooling set point of 23 °C, and it was enabled when PPD exceeded 10%. Energy related to air conditioning was subsequently obtained from the simulation model results.

In both cooling methods, the clothing adjustment was also applied to investigate the cumulative effects on comfort.

Activity Adjustment

People have the ability to reduce or increase their activity levels in spaces. In hot climate countries, people alternate between rooms and floor levels, following best internal conditions as a method to achieve thermal comfort. They change their activity level when feeling thermally uncomfortable, or move to another space when possible.

The simulation model uses a fixed metabolic rate level of (1.5 met) which represents an average type of activity level such as; cooking, light work, dancing or filing. This part of the study will introduce a second alternative of (1 met) which is a lower level of activity such as; reading, writing or sitting quietly (CIBSE, 2006). The metabolic rate was adjusted in a spreadsheet, in relation to the PMV rate. When the PMV was above 0.5, the metabolic rate was changed to 1 met, otherwise it remained at 1.5 met.

Activity adjustment was tested using both 'free-running' models and models with free cooling, in order to investigate the effect on thermal comfort and cooling requirements.

RESULTS

Free running models and clothes adjustment

The free running models, relying on shading to reduce solar gains, depend on window opening to reduce temperatures and maintain comfort levels. In the current and future weather, it was clear that the PPD rates were extremely high in summer as shown in Figure 4. The PMV were all positive, indicating that the discomfort was caused by overheating.

When clothing was adjusted, PPD was clearly reduced. The percentage of hours with PPD above 10% in the current weather reduced from 46% to 4%. But reductions in 2080 were not sufficient; the percentage of hours of PPD above 10% reduced from 88% to 38% as shown in Table 3.

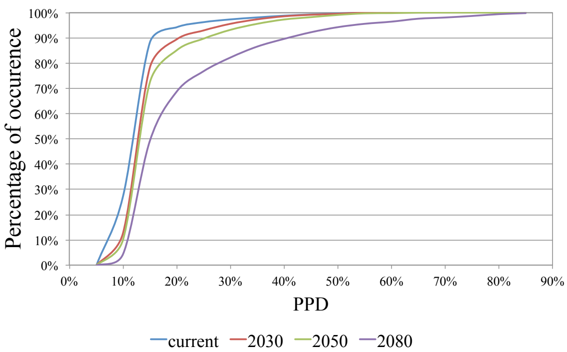

Figure 4 Cumulative frequency of occurrence for Summer PPD levels in different weather scenarios

Free cooling and clothes adjustment

Looking at the free cooling results in Table 3 in comparison to the free running models with fixed clothing, an improvement in the PPD was noticed, due to the expected reduction in internal temperatures. But in 2080, free cooling was still unable to reduce the PPD below 10%.

This reduction in PPD required energy use. Energy related to free cooling was calculated for the summer period and the amount of energy required is shown in Table 2.

Comparing the free cooling reductions, with the ones achieved by merely adjusting clothing levels, it is clear that the latter resulted in higher reductions in the percentage of hours of PPD above 10%. In the current weather, changing the clothing resulted in 28% more reductions than free cooling. In 2030, the reduction was 26% and in 2050 it was 24%. In 2080 neither of the methods achieved PPD of less than 10% but changing clothing achieved further reduction of 42% than free cooling (Table 3).

Furthermore, using cumulative frequency of occurrence analysis as shown in Figure 5, demonstrates the ability of clothing adjustment in different weathers to achieve lower PPD levels than free cooling.

Adjusting clothing with free cooling resulted in further reductions especially in PPD above 20%, with only 4% of the hours above 20% PPD in 2080, but the number of hours above 10% was still high (Table 3).

Table 2
Cooling energy demand

MODEL	FREE COOLING (KWH)	AIR CONDITIONING (KWH)
Current DSY	1265	1167
2030 DSY	1650	1826
2050 DSY	1666	1989
2080 DSY	1643	3528

Air conditioning and clothing adjustment

Air conditioning with cooling set point of 23°C was added to the simulation model, as result of the inability of free cooling alone to provide thermally comfortable conditions.

As shown in Table 3 air conditioning without any clothing adjustment, was not sufficient to improve thermal comfort. Percentage of hours with PPD higher than 10% was 5% in the current weather and up to 31% in 2080 over the whole summer.

Although the PPD level was brought down to an acceptable level using the clothing adjustments, the corresponding energy demand increased, as shown in Table 2.

Free running models with both clothing and activity adjustment

A combined adjustment of clothing and activity in the free running models resulted in a considerable improvement in thermal comfort, as shown in Table 3, providing a better option than free cooling combined with clothing adjustment.

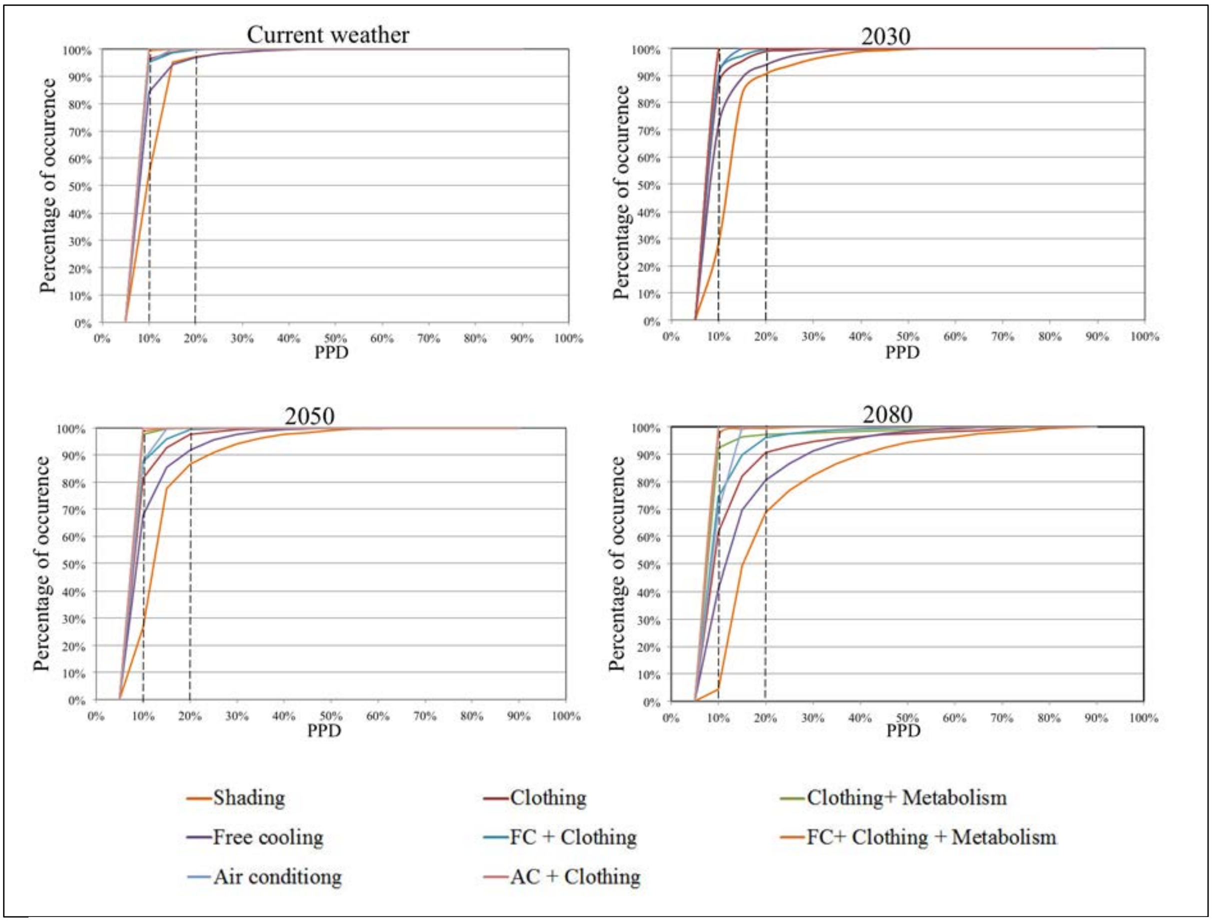

Figure 5 Cumulative frequency of occurrence of PPD levels

In 2080 the total hours with a PPD above 10% was reduced to 8%, highlighting the effectiveness of adjusting the personal variables in comparison to free cooling alone which resulted in a high percentage of 59% above 10% PPD as shown in Table 3 and Figure 5.

Free cooling with both clothing and activity adjustment

The flexibility in activity levels and clothing accompanied by free cooling resulted in a further reduction of PPD levels, but the improvements did not exceed the results achieved in the free running models, except in 2080, as shown in Table 3 and Figure 5.

DISCUSSION

The results indicate that personal variables can be used to improve thermal comfort. Changing the clothing and activity levels ensured thermal satisfaction of occupants up to the summer conditions of 2050.

Although it might be obvious that buildings with a certain number of cooling degree hours would require mandatory free cooling, this is not so obvious in a building that was designed for the current climate and that it is gradually going through climate change. Such buildings will not necessarily have somebody routinely preforming dynamic simulations on them, and the building occupants may be unaware of the changing requirements for maintaining the internal conditions.

In 2080, high level of discomfort occurs, which would probably require air conditioning. However, applying the change of occupant behaviour reduced the level of required cooling. The results indicated that having a cooling set point of 23°C was not sufficient until the flexibility of clothing was introduced.

Human thermal expectations and habits are significant factors in their reactions to increasing temperatures. The increasing prices of energy and environmental awareness will motivate people to resort to adaptation methods rather than energy consuming solutions. The occupants of the case study manage to achieve a zero carbon performance with minor behavioural adjustments when required.

As the thermal comfort settings in IES VE only affect the results in a post-simulation mode, taking the simulation results on the face value may lead to unnecessary specification of air conditioning. The work presented here shows how the simulation results can be explored in more detail so as to avoid over-specification of mechanical equipment and minimisation of energy consumption and carbon emissions.

Table 3
Percentage of hours with a PPD above 10% & 20% during summer (1st June-30th September)

PPD HOURS	CURRENT DSY		2030 DSY		2050 DSY		2080 DSY	
	ABOVE 10%	ABOVE 20%	ABOVE 10%	ABOVE 20%	ABOVE 10%	ABOVE 20%	ABOVE 10%	ABOVE 20%
Free running with fixed clothing	46%	3%	71%	9%	73%	13%	88%	29%
Free running with adjusted clothing	4%	0%	13%	1%	19%	2%	38%	9%
Free cooling with fixed clothing	16%	3%	28%	6%	32%	8%	59%	20%
Free cooling with adjustable clothing	5%	0%	9%	0%	12%	1%	26%	4%
Air conditioning with fixed clothing	5%	0%	10%	0%	12%	0%	31%	0%
Air conditioning with adjustable clothing	0%	0%	0%	0%	0%	0%	0%	0%
Free cooling with adjusted clothing & metabolism	1%	0%	1%	0%	1%	0%	4%	1%
Free running with adjustable clothing and metabolism	0%	0%	1%	0%	2%	0%	8%	3%

CONCLUSIONS

The Zero Carbon House model was used to test the extent to which human behaviour could reduce energy demand arising from the climate change. The study focused on summer periods in the current and future weather.

Two personal variables from Fanger's thermal equation were investigated; the resistance of clothing and the metabolic rates. The investigation was carried out through adjusting the corresponding levels, in order to test the extent these parameters can help achieve thermal comfort as well as energy reduction.

Although it might be obvious that the strategies used would reduce discomfort, this is not necessarily recognized in a building whilst going through climate change over a long period of time.

The IES-VE software used in this study does not take into account the ability of people to adapt to changing temperatures, as clothing rate and metabolic rate are both set as single fixed values for entire year and applied in a post-processing mode during the review of simulation results. This can lead to considerable overestimates of cooling and heating loads, especially as these settings are not commonly adjusted by the software users.

Applying behavioural changes, in the form of clothing and activity changes, resulted in eliminating any demand for cooling in the current weather, as well as in 2030 and 2050, using DSY weather files.

The extreme conditions expected in 2080 would require additional cooling, however the adaptation in the human behaviour needs to be taken into account in the cooling load estimates.

The results highlight the importance of taking the human ability to adapt to the surroundings into account. That is in addition to the physical mitigation and adaptation strategies in the building design, such as solar shading and thermal mass. With the increasing energy prices and the carbon emissions reduction targets, that would be the recommended path to follow before resorting to cooling systems.

These results should not be generalised, as they correspond to a specific case of the Birmingham Zero Carbon House. However, the paper demonstrates a method that could be applied to study thermal comfort in relation to human behaviour in modelling and simulation of any other building.

The future work will include a further analysis of heating load reductions during winter months using the same methodology.

ACKNOWLEDGEMENTS

The instrumental monitoring has been partially funded by the Higher Education Innovation Fund. Collaboration with Mr John Christophers of the Zero Carbon House is gratefully acknowledged.

REFERENCES

ASHRAE 2003. ASHRAE Standard: Thermal Environmental Conditions for Human Occupancy. Atlanta.

ASHRAE 2007. AHRAE:90.2 Energy Efficient Design of Low-Rise Residential Buildings. Atlanta.

Boardman, B., Darby, S., et al 2005. 40% House. Oxford: Environmental Change Institute.

Chan, A. L. S. 2011. Developing future hourly weather files for studying the impact of climate change on building energy performance in Hong Kong. Energy and Buildings, 43**,** 2860-2868.

CIBSE 2006. CIBSE Guide A.

De Dear, R. J. Outdoor climatic influences on indoor thermal comfort requirements. Thermal Comfort: Past, Present, and Future, 1994 Watford, UK. Building Research Establishment, 17-37.

Fanger, P. O. 1970. Thermal Comfort, Copenhagen, Danish Technical Press

HM, G. 2006. Climate Change- The UK Programme 2006, Norwich, UK: The Stationary Office.

Hulme, M., et al 2002. Climate Change scenarios for the United Kingdom: The UKCIP02 Scientific Report. Norwich, UK: University of East Anglia.

ISO 1984. Moderate thermal environments: determination of the PMV and PPD indices and specification of the conditions of thermal comfort, Switzerland, International Organization for Standardization.

Jankovic, L. & Huws, H. 2012. Simulation Experiments with Birmingham Zero Carbon House and Optimisation in the Context of Climate Change. In: ENGLAND, I. (ed.) Building Simulation and Optimisation 2012. Loughborough: IBPSA.

Kim, G., et al 2011. Comparative advantage of an exterior shading device in thermal performance for residential buildings. Energy and Buildings.

Murray, S. N., Rocher, B. & O'Sullivan, D. T. J. 2011. Static Simulation: A sufficient modelling technique for retrofit analysis. Energy and Buildings.

Perez-Lombard, L., Ortiz, J. & Pout, C. 2008. A review on buildings energy consumption information. Energy and Buildings, 40 (2) 394-398.

Porritt, S. M., et al 2012. Ranking of interventions to reduce dwelling overheating during heat waves. Energy and Buildings, 26**,** 285-300.

UKCIP. 2010. UKCP09: UK Climate Projections [Online]. Available: http://www.ukcip.org.uk/ukcp09/key-findings/summer-pmean/ [Accessed 26/10 2011].

UKCP09. 2010. Probability [Online]. Available: http://ukclimateprojections.defra.gov.uk/content/view/1118/690/ [Accessed Oct 2011.