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Energy Procedia 00 (2016) 1–6
Energy Procedia
www.elsevier.com/locate/procedia

The 8th International Conference on Applied Energy ICAE2016

Performance of UK dwellings in projected future climates

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Abstract

Projected increases in temperature due to the changing climate are likely to exacerbate overheating in buildings, especially in UK domestic buildings that are designed for the existing temperate climate. Due to the long life span of buildings, over two-thirds of dwellings in 2050 are projected to be the buildings built before 2000. Adaptability of the existing buildings to future climates, therefore, needs to be assessed to see if they will remain comfortable without resorting to mechanical cooling. This research evaluated occupant thermal comfort in a semi-detached UK residential building with different strategies of window openings under weather scenarios at different time scales: present-day, 2030s, 2050s and 2080s, using dynamic thermal simulation in five UK cities: London, Birmingham, Manchester, Edinburgh and Belfast. Standard EN 15251 was used to analyse the freerunning building to investigate the effect of various window opening schedules on overheated hours. The findings highlighted that opening windows for longer time would reduce uncomfortable hours above the threshold operative temperature. However, the strategy on its own was not enough to maintain thermal comfort at all occupied hours in 2050s. Further adaptive measures, especially a combination of passive strategies including envelope refurbishment, need to be investigated for optimal adaptation.

Selection and/or peer-review under responsibility of ICAE

Keywords: Climate change; Dwellings; Adaptation; Thermal comfort; Overheating; United Kingdom

1. Introduction

Globally, the built environment is an important factor in understanding the cause and effect of climate change because of: (a) their embodied and operational energy use that contributes to global warming; i.e. *cause* and (b) overheating in buildings due to increased temperature; i.e. the *effect* [1]. Overheating in British homes is of increasing concern even for the UK′s temperate maritime climate as high internal temperature is likely to occur more frequently in future due to global warming, resulting in uncertainty of thermal comfort and building performance [2, 3]. The latest UK Climate Projection (UKCP09) provides probabilistic climate change scenarios for the UK that highlights a rise in summer average temperatures in London by 1.3°C – 4.6°C by 2050s [4] and up to 5.4°C in south England by 2080s since 1990s [5]. The Chartered Institution of Building Services Engineers (CIBSE) emphasized that summer overheating can exacerbate thermal discomfort in European buildings [6] as high internal temperatures often lead to discomfort or even

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be life-threatening. Residential buildings are mostly built with heating system and natural ventilation in the UK. Occupants usually adapt their comfort in summer by opening windows to cool high internal temperatures. Compared with other adaptive behaviour such as door open and blind in natural ventilated buildings, window open is more effective to control indoor environment [7]. In thermal comfort surveys of 15 British buildings, 83% of people choose to open windows when outdoor air temperature is over 22.8°C [8]. Shikder et al. [2] found that opening windows for 8 hours per day can reduce 286 hours of temperature over 23°C for London area in 2050s. Night ventilation is able to cool the building shell overnight and reduce degree hours by 67% in the living room of a UK mid terrace house [9]. Contrarily, insufficient ventilation will lead to health issues such as poor air quality and overheating risks in UK homes in summer [10].

The design, operation and management of buildings rely heavily on weather, hence their adaptation to climate change to prevent overheating is becoming more vital [11]. The adaptive comfort standards have been widely applied since comfort zones or neutral temperatures have been found to be related to outdoor temperatures and people are thought to have opportunities to adapt to thermal comfort by adjusting clothing or activities [12, 13, 14]. Standard EN15251 is more flexible to be applied in natural ventilation buildings and allows people open windows or adjust clothing [15] while ±2°C and ±3°C from neutral comfort temperature are applied to reflect 6% and 10% of Predicted Percentage of Dissatisfied (PPD) in Fangers model [16].

2. Methodology

Climate scenarios from UKCP09 weather database have been applied on the EnergyPlus models of a typical UK semi-detached dwelling c. 1990s in five geographically-dispersed UK cities to assess if internal operative temperatures meet summertime comfort in the present day and 2080s. Figure 1a shows the location: London (51.49°N, 0.45°W), Birmingham (52.44°N, 1.74°W), Manchester (53.34°N, 2.26°W), Edinburgh (55.94°N, 3.32°W) and Belfast (54.66°N, 6.23°W) which aims to gather different dimensions of climate in the UK. As illustrated in Figure 1b the two-storied residential building is south-facing comprising two mirrored houses sharing a wall in the middle and a pitched roof with dividers in the attic. Each house is occupied by a typical UK working family which is supposed to be a pair of parents and two children. The floor plans in Figure 1c clearly demonstrate the layouts in the ground floor and first floor for a traditional UK home. As residents spent most of their time in bedrooms, one of the bedrooms (master bedroom facing south) in the first floor has been chosen to assess if the room suffers overheating with scheduled occupancy and future climate scenarios. The dwelling is assumed to be fully occupied during weekends (00:00 to 24:00) and partially occupied (17:00 to 08:00) during weekdays and bedrooms are assumed to be occupied for eight hours (22:00 to 06:00) with fractional occupancy at intermediate hours, as illustrated in Figure 1d.

Window opening is considered to be adopted as the only measure to reduce the risk of overheating during summer to estimate the vulnerability of UK dwellings to climate change without mechanical cooling. The dynamic thermal model has been built to simulate indoor operative temperature to assess occupant thermal comfort by changing windows opening duration: (a) opening windows for the whole day [00:00−24:00], (b) opening windows during the day [07:00−18:00], and (c) opening windows during the night [18:00−07:00]. The simulations were run for whole year to account for the thermal storage effect but only summertime (June to August) performance was analysed. The full dataset (of results) are avialable for download at [17].

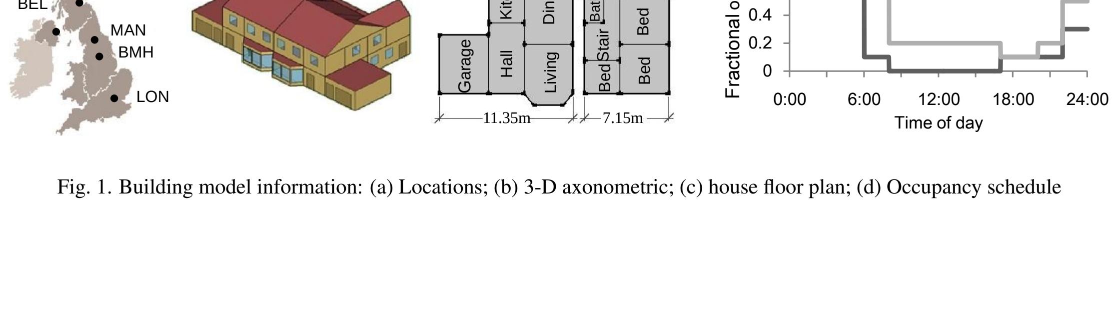

Fig. 1. Building model information: (a) Locations; (b) 3-D axonometric; (c) house floor plan; (d) Occupancy schedule

3. Results and discussion

Results of overheated hours with whole-day windows opening for all selected cities from the present day to 2080s have been explored into table 1. In the adaptive model for naturally ventilated dwellings, comfort zone falls in the range of 2 or 3°C from thermal comfort temperature (T_c) which represents high and normal levels of expection, or 6% and 10% Predicted Percentage of Dissatisfied (PPD) in Fanger's PMV model [18]. It is significant that the future climate change will have the greatest impact on London and Birmingham which they have more risks of suffering from overheating in future. London has about 5 times and 8 times of operative temperatures over 2°C and 3°C respectively compared with Edinburgh and Belfast. According to Table 1, overheating gets worse in the future as internal operative temperature increases as a result of global warming. Especially for London, over half of summer time in the 2080s will be too hot and uncomfortable for UK naturally ventilated dwellings.

Figure 2 presents the variation of zone (selected bedroom) operative temperatures for dwelling located in five investigated cities with UKCP09 probabilistic climate projections of present day, 2030s, 2050s and 2080s. The current climate seems to perform well for all locations with only a few sudden high temperature peaks. As the time goes from 2030s to 2080s, overheating scenarios are likely to occur more and more often. Especially London and Birmingham are expected to suffer overheating more seriously than other cities from 2030s. In London in 2080s, the half of summertime is assessed to be overheated, which is unacceptable.

Operative temperature exceeding the upper threshold can be seen as overheating when people need to take measures to adapt to high temperatures. Figure 2 reveals that the adaptive comfort temperature is increased when indoor and outdoor temperatures increased. The neutral comfort temperature will change from around 24°C to 26°C from present day to 2080s for occupants in London. When people get used to the increasing high temperatures in future, the most unstable factor which will severely harm occupant health is the more and more frequent sudden peaks of high temperatures. From Figure 2a and 2b, the peak high operative temperatures are coming out often which shows potential risks of heat wave. A few hot days is found to be worse than a longer warm spell for occupants as people suffer more discomfort when temperatures increase suddenly and even worse when the rise is dramatic instead of a gradual rise [19].

The overheating in dwellings is dramatically influenced by the locations of cities, the higher latitudes experiencing less overheating. Comparing London with Belfast for different locations in South and North of the UK, the difference in overheating hours are huge. The lower latitude cities are more vulnerable to future climate change such as London and Birmingham. Table 1 illustrates that the average indoor operative temperature in London will increase significantly in the future with a rise of up to 2°C in the summer by the 2050s and 2.37°C by the 2080s. The maximum difference from the operative temperature to the adaptive comfort neutral temperature for the bedroom can reach to 7.84°C in the 2050s for the domestic building with opening windows for 24 hours in London. Edinburgh and Belfast do not suffer from overheating until 2080s. The overheating hours remains below 100 before 2080s for both cities with higher latitude.

Figure 3a compares three modes of opening behaviour by observing the variation of hourly indoor (bedroom) temperatures in a present summer day in London. It is obvious that 24 hours opening performs better than only opening during the day or night. The most difference is no more than 1°C for operative temperature to achieve neutral comfort when adaptive comfort temperature is between 23°C and 24°C.

Table 1. Hours above the upper limit of thermal comfort temperature with whole-day windows opening strategy

	Hours above upper comfort threshold temperature									
Climate	London		Birmingham		Manchester		Edinburgh		Belfast	
	$T_c + 2$	$T_c + 3$	$T_c + 2$	$T_c + 3$	$T_c + 2$	$T_c + 3$	$T_c + 2$	$T_c + 3$	$T_c + 2$	$T_c + 3$
Presentday	46	15	44	26	13	2	8	0	8	0
2030s	334	170	224	114	79	34	100	36	49	10
2050s	512	325	339	161	230	140	113	45	84	40
2080s	1054	858	661	462	317	151	235	111	209	104

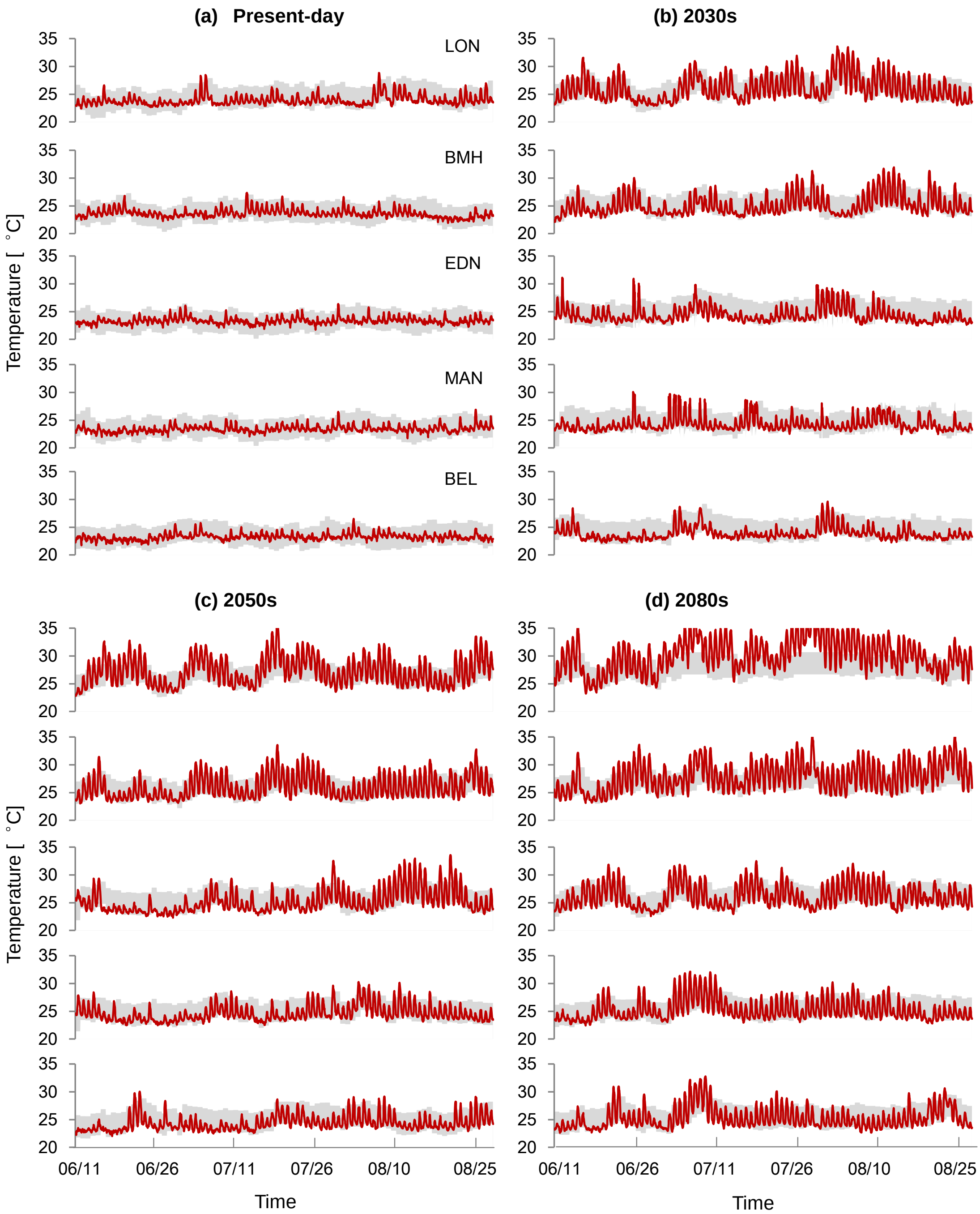

Fig. 2. Zone operative temperatures in UK cities with 24 hours opening schedule for: (a) Present-day; (b) 2030s; (c) 2050s; (d) 2080s

Compared with daytime opening schedule, night ventilation through opening windows is more effective and important for occupants although high temperatures occur in the afternoon. Opening windows with adequate night ventilation will be a good strategy for summer overheating in the future. As the bedrooms are occupied for sleeping at night and low temperature outdoor air can cool high indoor temperatures, night opening behaviour is able to achieve thermal comfort successfully. In the present day climate all three opening behaviours can achieve acceptable comfort as occupied temperatures with daytime opening are

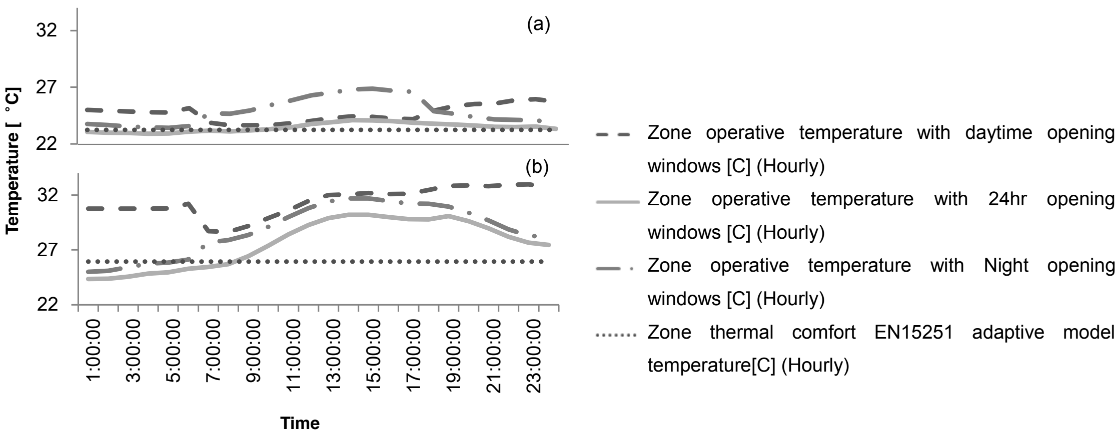

Fig. 3. Hourly bedroom operative temperature in a summer day in London with different opening schedules for (a) Present day; (b) 2080s

under 26°C which has less than 3°C difference from adaptive neutral comfort.

Figure 3b compares three opening schedules in the 2080s for a summer day in London. Night ventilation can provide better comfort performance than daytime ventilation when outdoor temperature gets higher in future. However, security and privacy during nighttime needs to be addressed. The internal operative temperature is high in 2080s, especially in London. Opening windows during the daytime is not enough to reduce high internal temperatures. Also, the integrated effects of daylight and corresponding solar heat gain needs to assessed to fully appreciate the impact of opening windows during daytime [20]. People may have to open windows during the night for thermal comfort. Night ventilation seems to be still effective to reduce night temperatures to satisfy occupants. It is surprised that room operative temperatures using night and 24 hours window opening behaviours have nearly similar trend in variation with limited difference of less than 2°C in their most difference. This phenomenon shows that the higher the temperatures the lower effect of opening windows during the day will give.

4. Conclusion

To minimize summer overheating risks in future, adequate adaptation measures should be applied to reduce the impact of future climate change on the performance of domestic buildings in the UK. This study identified that thermal comfort of residential occupants will be significantly influenced by the aggravated summer overheating due to global climate warming in the future, especially for low latitudes in the UK with high risks of overheating post 2050s. Indoor operative temperature can reach very high in a short period which will make the occupants unable to tolerate the sudden peaks in room temperature in the 2080s. Additional attention should be paid to overcome sudden onset of hot days, especially for newly built highly-insulated residential buildings with higher U-values that may reduce heating energy consumption [21] in the present climate but is likely to increase overheating risks in future warming climates [9]. Policies and regulations need to consider thermal performances of materials for present and future climates alike, and promote education among the stakeholders [22] to encourage resilient thinking and practice.

The study also identified that internal temperatures will be dramatically influenced by the duration of opening windows. The result of this analysis indicated that adequate air ventilation will be still an effective measure in controlling indoor climate to prevent summer overheating in future. The longer window the occupants open, the more stable and comfort the indoor environment will be in the ventilated buildings. Opening windows is suggested to be able to play certain role in cooling high internal temperatures to prevent overheating risks even in London in the near future but the effect will be gradually reduced as the temperatures increase. Compared with daytime ventilation, the 2080s model showed that night ventilation is more effective than daytime ventilation in cooling internal operative temperatures when outdoor temperatures are getting higher in future. However, as curtains or blind are not considered in this model, there will be certain influence for window ventilation to cool down room temperatures. With shading devices, sunlight will be blocked to reduce heat gain in order to decrease room temperatures during the day. Moreover, as the model focused on window opening and indoor temperature variation, safety may be an issue when occupants open windows at night. Finally, there is limitation to the use *opening windows* as the only adaptation measure. Cooling down a building during off-peak electricity tariffs may be another solution, for which the control of the building systems need to integrate well with the proposed smart grid solutions [23], as well as optimising the use solar PV electricity for cooling, where available. The combination of various adaptive measures should be applied to tackle the challenge of summer overheating for domestic buildings in the future.

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