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Measured indoor temperatures, thermal comfort and overheating risk: Post-occupancy evaluation of low energy houses in the UK

Rory V. Jones[a]*, Steve Goodhew[b], Pieter de Wilde[a]

[a]*Building Performance Analysis Group, School of Architecture, Design and Environment, Plymouth University, Drake Circus, Plymouth, PL4 8AA, UK*

[b]*Environmental Building Group, School of Architecture, Design and Environment, Plymouth University, Drake Circus, Plymouth, PL4 8AA, UK*

Abstract

There is growing concern in Western Europe that higher insulation and air tightness of residential buildings leads to increased overheating risk. This paper discusses temperature monitoring from identical houses in the Southwest of the UK that were built to low energy standards (Code for Sustainable Homes Level 5). The temperature data were analysed using both established static overheating criteria (CIBSE Guide A) and an adaptive thermal comfort standard (BSEN15251). The houses can be considered uncomfortably warm during summer and are at risk of overheating. The study suggests that occupant behaviour plays an important role in reducing or increasing internal temperatures.

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Keywords: Low energy social houses, Thermal comfort, Overheating, Measurement, Post-occupancy evaluation

1. Introduction

The domestic sector accounted for 26.4% of final UK energy consumption in 2011, with space heating accounting for 61% of the sector's energy consumption [1]. Consequently, winter temperatures and reducing the energy demand for space heating has been the main focus of attention for the UK government and research community. However, overheating in homes has been recognised as an unintended consequence of a drive in recent decades towards reducing space heating energy use.

* Corresponding author. Tel.: +44 01752 585198; fax: +44 01752 585155.
E-mail address: rory.jones@plymouth.ac.uk

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Previous studies have demonstrated that even in the current UK climate, overheating is possible in residential buildings [2,3]. In future, this risk is likely to further increase due to the effects of global climate change [4]. A further concern is that increasing indoor temperatures in homes may lead to the installation of mechanical air conditioning, which would be, for the UK, a new source of greenhouse gas emissions.

Previous studies have used dynamic thermal modelling to assess the risk of overheating for different construction standards [5,6]. Although modelling studies are useful, by their very nature they are based on assumptions and simplifications of the full complexity of real buildings. Some of these are crucial when it comes to overheating, especially where they pertain to occupant behaviour (window opening, ventilation rates, presence in specific rooms). In contrast, measurement of indoor temperatures in dwellings provides direct observations. Monitoring studies are however expensive and time consuming, meaning field data of indoor temperatures in UK homes remains rather limited [2,3,7].

As low energy homes (i.e. exceeding regulatory compliance) are only recently emerging in the UK housing stock, and even fewer are subject to Post-Occupancy Evaluation (POE), little is known about their actual indoor temperatures and risk of overheating.

This paper presents one of the first studies of thermal comfort and overheating risk in UK low energy homes. Indoor temperatures monitored in the living rooms and main bedrooms of two identical Code for Sustainable Homes (CfSH) Level 5 mid-terrace houses are examined using both established static overheating criteria (CIBSE Guide A) and an adaptive thermal comfort standard (BSEN15251). These measurements are compared with an identical mid-terrace house constructed to minimum compliance only (i.e. building regulations). The houses were all identical in layout, building services installed and orientation, only the construction standard (CfSH and minimum compliance) varied.

2. Methodology

This paper presents measured temperature data collected during the summer of 2013 from two Code for Sustainable Homes (CfSH) Level 5 mid-terrace houses and an identical mid-terrace house built to current building regulations only (Bldg Regs) located in Torquay, UK. The CfSH [8] is a voluntary national standard for the sustainable design and construction of new homes. The code has various levels', Level 5 relates to a home that is twice as thermally efficient as what is currently required by building legislation.

2.1. Data collection

As part of a larger Post-Occupancy Evaluation (POE) to assess the actual operational performance of the dwellings, calibrated HWM Ecosense temperature loggers (±0.3°C) were used to record indoor air temperatures in the living rooms and main bedrooms of the dwellings, as well as outdoor air temperature. The time interval for data logging was every 5 minutes. The loggers were sited away from heat sources and direct sunlight. Temperature data were collected from 1st July to 31st August 2013, which is the period of time focussed on in this paper, herein referred to as the ‘summer period’.

During the summer period, the outdoor air temperature ranged from 10.7°C to 35.1°C. The monitoring period was characterised by two distinct ‘hot spells’, where the average daily temperature exceeded 19°C for five and fourteen successive days. The 2013 summer period was substantially warmer than the average daily outdoor temperatures for Torquay between 1961 and 2007. The measured indoor temperatures of the houses can therefore be considered in the context of a warmer than average summer, with two distinct hot spells.

2.2. Temperature assessment criteria

The indoor temperatures were gathered from the living rooms and bedrooms of the houses operating in free-running mode. Thermal comfort and overheating risk were assessed using both established static overheating criteria according to CIBSE Guide A [9] and the adaptive thermal comfort standard BSEN15251 [10].

CIBSE Guide A recommends summer indoor comfort temperatures in dwellings of 25°C for living rooms and 24°C for bedrooms and provides overheating criteria for evaluating the predictions of thermal models, which state that there should be no more than "1% annual occupied hours over operative temperature of 28°C" for living rooms and "1% annual occupied hours over operative temperature of 26°C" for bedrooms. For bedrooms, it is also noted that "sleep may be impaired above 24°C" and that "temperatures at night should not exceed 26°C unless ceiling fans are available". For the assessment of overheating risk, previous studies [2,3,7] have used 5% of occupied hours over 25°C and 1% over 28°C as allowable annual exceedances for living rooms, and 5% of occupied hours over 24°C and 1% over 26°C for bedrooms. As the static criteria are used to assess indoor temperatures during the summer period only results exceeding 1% and 5% indicate rooms that are uncomfortably warm, not overheating as defined by CIBSE Guide A.

BSEN15251 provides comfort envelope thresholds for each value of the exponentially weighted running mean of the daily external temperature (Trm) within the range 10 < Trm < 30°C for the assessment of both warm (upper threshold) and cold (lower threshold) thermal discomfort. The adaptive criteria allow the assessment of thermal comfort over any time period. In this study, 5% of hours above the Category II upper threshold was used as an indication of warm discomfort.

3. Results

The average indoor temperatures in the living rooms and main bedrooms of the three houses are shown in Table 1. The thermal comfort and overheating risk results obtained using the CIBSE Guide A static overheating criteria and BSEN15251 adaptive thermal comfort standard are presented in Table 2.

Table 1. Mean indoor temperatures during occupied hours in the living rooms and main bedrooms of the houses

House (Construction standard)	Living room (08:00-22:00)	Living room (18:00-22:00)	Bedroom (23:00-07:00)
	Mean (°C)	Mean (°C)	Mean (°C)
House 1 (CfSH Level 5)	25.1	25.4	25.0
House 2 (CfSH Level 5)	25.5	25.5	26.3
House 3 (Bldg Regs)	21.5	21.5	20.9

Table 2. Thermal comfort and overheating risk results for the three houses using the CIBSE Guide A static overheating criteria and BSEN15251 adaptive thermal comfort standard

House (Construction standard)	CIBSE Guide A Static Criteria					
	Living room (08:00-22:00)		Living room (18:00-22:00)		Bedroom (23:00-07:00)	
	% occupied hours over 25°C	% occupied hours over 28°C	% occupied hours over 25°C	% occupied hours over 28°C	% occupied hours over 24°C	% occupied hours over 26°C
House 1 (CfSH Level 5)	**50.4**	**1.0**	**54.5**	**1.3**	**71.5**	**25.6**
House 2 (CfSH Level 5)	**59.9**	0.0	**61.6**	0.0	**97.5**	**60.6**
House 3 (Bldg Regs)	1.2	0.0	1.3	0.0	3.4	0.0

House (Construction standard)	BSEN15251 Adaptive Criteria						
	Living room (08:00-22:00) % hours						
	Above Cat III-up	Above Cat II-up below Cat III-up	Above Cat I-up below Cat II-up	Between Cat I-up and Cat I-low	Below Cat I-low above Cat II-low	Below Cat II-low above Cat III-low	Below Cat III-low
House 1 (CfSH Level 5)	0.0	0.0	1.8	93.4	4.2	0.5	0.0
House 2 (CfSH Level 5)	0.0	0.0	1.6	97.7	0.6	0.0	0.0
House 3 (Bldg Regs)	0.0	0.0	0.0	6.6	23.5	32.6	37.3
	Living room (18:00-22:00) % hours						
House 1 (CfSH Level 5)	0.0	0.0	2.9	95.5	1.6	0.0	0.0
House 2 (CfSH Level 5)	0.0	0.0	2.9	97.1	0.0	0.0	0.0
House 3 (Bldg Regs)	0.0	0.0	0.0	9.0	24.8	26.5	39.7
	Bedroom (23:00-07:00) % hours						
House 1 (CfSH Level 5)	0.0	0.0	1.6	97.5	0.9	0.0	0.0
House 2 (CfSH Level 5)	0.0	4.8	17.6	77.6	0.0	0.0	0.0
House 3 (Bldg Regs)	0.0	0.0	0.0	0.5	7.7	29.6	62.2

4. Discussion

According to the current study, even in the current climate of the UK, houses constructed to higher thermal performance standards are already at risk of overheating during the summer. The evidence suggests that the recent drive towards improved insulation and air tightness standards may be at the expense of summertime thermal comfort. The work presented in this paper demonstrates that the implementation of advanced performance standards may require more careful consideration.

The results show that the living rooms and bedrooms of the CfSH Level 5 houses had average indoor temperatures exceeding the recommended summertime temperatures of 25°C and 24°C respectively. Furthermore, the analysis using the static criteria suggested that the living rooms in the CfSH Level 5 houses were generally warmer than would be considered acceptable by the building occupants, but only limited periods with extremely high internal temperatures (greater than 28°C) throughout both the day (08:00-22:00) and evening (18:00-22:00) were identified. At night (23:00-07:00), the bedroom temperatures in the CfSH Level 5 houses were very warm and thereby at increased risk of overheating. The identical building regulations house however had both lower average indoor temperatures consistent with summer thermal comfort expectations and performed within the acceptable bandwidth for warm discomfort in both the living room and bedroom.

As the external surface to floor area ratio, building services installed and orientation were identical between the CfSH Level 5 and building regulations houses, the results obtained therefore suggest that the improved construction standard could be responsible for the increased internal temperatures and overheating risk identified.

Furthermore, as CfSH Houses 1 and 2 were identical, the variations in thermal comfort and overheating risk observed are likely to reflect the role of occupant behaviour [11,12,13,14]. The occupants of House 1 may have taken more effective actions to mitigate the higher internal temperatures, such as opening windows and doors, creating shade using curtains or blinds in areas exposed to direct solar radiation and switching off heat-producing domestic appliances. It is also possible that the occupants of House 2 may simply spend more time in the main bedroom and their presence as a source of heat could have resulted in increased internal temperatures. Further empirical evidence is needed about the relationship between occupancy and the avoidance of high internal temperatures and overheating in domestic buildings. Such work is currently being undertaken in the IEA Annex 66 [15].

The results of the adaptive thermal comfort standard indicated that the CfSH Level 5 houses generally performed within the acceptable bandwidth for warm discomfort as defined in BSEN15251. The main bedroom temperatures in House 2 however tended towards the upper threshold, suggesting warm discomfort for the building occupants. In the building regulations house this was not the case.

5. Conclusions

The results of the study showed that the living rooms and bedrooms of the CfSH Level 5 houses had average indoor temperatures exceeding the recommended summertime temperatures of 25°C and 24°C. Furthermore, the analysis using the static overheating criteria (CIBSE Guide A) suggested that the living rooms in the CfSH Level 5 houses were generally warmer than would be considered acceptable by the building occupants. Limited periods with extremely high internal temperatures (greater than 28°C) were also identified. The bedroom temperatures in the CfSH Level 5 houses were very warm and thereby at increased risk of overheating.

By comparison, the building regulations house had both lower internal temperatures consistent with summer thermal comfort expectations and performed within the acceptable exceedances for warm discomfort in the living room and main bedroom.

This work also identified some variations in average internal temperatures and thermal comfort between the living rooms and main bedrooms of the two identical CfSH Level 5 houses. This finding suggests that the behaviour of the occupants may play an important role in reducing or increasing temperatures in homes. Additional work is needed to understand the effectiveness of potential occupant behaviours, such as window opening, closing curtains or blinds, and controlling ventilation to prevent excess warm air entering the dwelling during the warmest parts of the day. Further research is also needed to establish the full extent of the potential overheating risk in a broader range of dwelling types constructed to advanced performance standards. Research on the impact of occupant behaviour on temperatures is ongoing, with presence and window actions being measured over a three year timeframe.

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Biography

Dr Rory Jones is a Research Fellow in the Building Performance Analysis Group of the School of Architecture, Design and Environment at Plymouth University, UK. He received his PhD from the Building Energy Research Group of the School of Civil and Building Engineering at Loughborough University, UK.