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Empirical assessment of summertime overheating risk in new, retrofitted and existing UK dwellings

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ABSTRACT

This paper statistically assesses the hourly internal summertime temperature datasets gathered during the summer of 2013 (May to September), from 63 dwellings across the UK. The sample consisted of unmodified dwellings (existing); dwellings with varying levels of fabric improvements (retrofitted) and dwellings constructed to higher levels of the Code for Sustainable Homes (new). Indoor and outdoor temperature data from bedrooms and living rooms from these homes were collected at five-minute intervals using temperature sensors. These data were processed and analysed for summertime overheating, using both static criteria (CIBSE Guide A) and the criteria associated with the EN15251 adaptive thermal comfort model (CIBSE TM52). The results show that despite a relatively cool summer, sufficiently high temperatures were found in a high proportion of dwellings, which were found to be overheated according to the CIBSE static temperature criteria, although the prevalence of overheating was found to be much lower when assessed by the adaptive method. Considerably higher temperatures were found in bedrooms, much higher than living rooms. Interestingly, dwellings with higher levels of insulation experienced overheating twice as frequently as uninsulated dwellings. Given the prevalence of overheating found across the sample, it is necessary to carefully consider this risk during the design and retrofit of homes, to avoid the growth of domestic air-conditioning in future.

KEYWORDS

Dwellings, overheating, UK housing, adaptive thermal comfort, indoor air quality

INTRODUCTION

Despite the relatively mild climate of the UK, concern has increased about summertime temperatures in dwellings due to the effects on occupant health of high temperatures and the possibility that these may occur more frequently with the forecast rise in global temperatures. Though overheating may be prevented by the use of air-conditioning, this will add, undesirably, to greenhouse gas emissions through increased energy use and refrigerant emissions. As most UK householders turn their heating off in the summer even when temperatures are comparatively cool, the fabric of the dwelling can provide a cool buffer against hotter weather. It is therefore important to study internal temperatures in dwellings to observe the relationship to construction, dwelling type and occupant characteristics.

With the implementation of the higher level of fabric efficiency under current UK Building Regulations, overheating in newly-constructed dwellings has become a concern, particularly due to the perception that it is caused by the ‘excessive’ levels of insulation required to reduce heat energy consumption and hence CO_2e emissions to meet the requirements of the UK Climate Change Act. With the focus on overheating has come a realisation that both the definition of, and the criteria for assessing overheating in naturally-ventilated residential buildings are inadequate (CIBSE, 2013).

Previous studies examining summer temperatures in UK dwellings have included Lomas and Kane (2013) who found, in a study of 230 dwellings in Leicester, that a sizeable proportion had temperatures outside the ranges anticipated by the BS EN 15251 model. Beizaee et al. (2013) performed a similar study based on 207 dwellings across the UK. This study found that a large proportion of living rooms and bedrooms had more than 5% of their occupied hours above the CIBSE recommended temperature thresholds of 25°C and 24°C respectively. Across the regions of the UK, warmer homes were found in the South East, the East, East and West Midlands, with cooler homes in the North East, North West and Yorkshire. The oldest dwellings (pre-1919) were found to be significantly cooler than more modern homes, solid wall houses cooler than those with cavity wall construction and detached homes cooler than those of other built-form types. This study also found that dwelling temperatures in cooler UK regions were correspondingly cooler than those in warmer regions, inferring from this that a further level of adaptation, dependent on region, is required.

The objective of this paper is to combine data collected from several studies to examine the variations between the different methods of assessing overheating and to examine the relationships between temperature and other environmental variables. The study is significant in that it contains data gathered from existing houses, both with retrofit energy efficiency improvements and without, and new houses built to the highest energy efficiency levels under the UK standards current at this time (DCLG, 2006). This allows the examination of the differing effects of built-in and retrofit energy efficiency measures and unimproved housing, whereas the previous studies lack the ability to make these distinctions.

METHOD

This study is based on data collected between 1 May and 30 September 2013 in nine different locations in the UK, ranging from Swansea in the west to Tyneside in the north and west London in the south. The data analysed for this paper come from one large-scale monitoring study and three smaller studies. The large-scale study, known as EVALOC, covered 57 existing dwellings in six locations across the UK. The dwellings in these locations include a mix of existing (unchanged) and retrofitted dwellings. For EVALOC, temperature data were collected via sensors linked to a wireless network within the house, from which it was transmitted to a webserver for accumulation and download as required for analysis. In some dwellings data were also acquired by individual ‘button’ loggers for direct download to a PC.

The three smaller studies each consisted of two new-built dwellings and were carried out as Building Performance Evaluation (BPE) studies, being accompanied by a detailed survey of the occupant satisfaction with the dwellings and a comparison dwelling as built with the original design. Because of the higher level of air-tightness enforced by Code for Sustainable Homes, all these houses have mechanical ventilation with heat recovery (MVHR) installed to provide ventilation and prevent condensation from excess humidity. Temperature data for the BPE studies were collected every five minutes from wireless sensors transmitted to a data-hub and uploaded over Global System for Mobile Communications network to a website for acquisition. The environmental data were limited to a period of between three and nine months with some gaps in the data due to the limitations of the data loggers. Sufficient data were collected over the summer period to assess overheating.

In all the studies, external temperature and RH were also collected by the same methods for all dwellings with the exception of C3 and C8 where external temperatures had to be extracted from nearby weather stations due to equipment failures. Table 1 lists the communities of dwellings and their relevant characteristics.

Table 1. Characteristics of study dwellings

	Location (Code) / setting	No. of dwellings: Date of construction mix
EVALOC	Community 1, South Wales (C1) / rural elevated	Total 11: pre-1919, 1919-44, 1965-80, 1981-90, post-1990
	Community 2, Merseyside (C2) / suburban sheltered	Total 12: 1919-44, 1945-64, 1965-80, 1981-90
	Community 3, North East (C3) / suburban sheltered	Total 10: 1919-44, 1945-64, 1965-80
	Community 4, Oxfordshire (C4) / rural elevated	Total 10: pre-1919, 1945-64, 1965-80, 1981-90
	Community 5, Yorkshire (C5) / urban elevated	Total 5: pre-1919
	Community 6, Midlands (C6) / urban sheltered	Total 9: pre-1919, 1919-44, 1965-80, 1981-90
BPE	Community 7, Wilts (C7) / urban sheltered	Total 2: new-build BPE
	Community 8, London (C8) / urban sheltered	Total 2: new-build BPE
	Community 9, Midlands (C9) / urban sheltered	Total 2: new-build BPE

Overheating assessment

Research on overheating in dwellings commonly employs two different methods of assessment published by the Chartered Institution of Building Services Engineers (CIBSE). For overheating criteria in non-air-conditioned buildings, CIBSE's Environmental Design Guide A (CIBSE, 2006) suggests that values for indoor comfort temperatures should be 25°C for living areas and 23°C for bedrooms. CIBSE notes that temperatures are expected to be lower at night with people finding that sleeping in warm conditions is difficult, particularly above 24°C. Environmental Design Guide A provides static benchmark summer peak temperatures and overheating criteria:

- 1% of annual occupied hours over 28°C in living rooms
- 1% of annual occupied hours over 26°C in bedrooms

For adaptive thermal comfort, the BS EN 15251 (BSI, 2008) criteria were developed taking the outdoor conditions and human adaptation into account by identifying comfort limits based on a running mean of external temperature and the quality of the thermal comfort required. Based on this, the CIBSE TM52 (CIBSE, 2013) document suggests a series of criteria by which the risk of overheating can be assessed or identified. The first criterion suggests that the number of hours during which the internal temperatures are 1 K higher or equal to the upper comfort limit during the period from May to September should not exceed 3% of occupied hours. For the adaptive assessment, the 'running mean' comfort temperature range was calculated using the external temperatures acquired for each locality.

For both methods of assessing overheating, priority is given to those hours during which each room is occupied. For this study, it is assumed that living rooms are occupied between 7 am and 11 pm and bedrooms are occupied for the remaining hours from 11 pm till 7 am. Treating only these periods as significant for overheating could be considered somewhat restrictive since a considerable proportion of the population work shifts and will need to sleep during the day at times of higher outside noise levels, precluding window opening etc.

RESULTS

Regarding external temperatures, localities in the north (including urban) and those in the rural localities of the south had the lower temperatures. Those in the urban areas of the south had the highest temperatures. Overall the analysis illustrated a fairly mild climate with only short intervals of high temperatures and comparatively low minima, which should enable householders to use night-time cooling if necessary. From cooling degree day (CDD) analysis it would appear that localities C1 and C5 had considerably warmer summers than usual, C3 and C7 somewhat warmer, C2, C8 and C9 were, more or less, as would be expected and C4 and C6 considerably cooler.

Overheating in bedrooms and living rooms

The most significant result from static overheating analysis for bedrooms is that only one dwelling, C3-H06, out of 63 dwellings in the dataset, does not exceed the 26°C limit. Five dwellings out of 34 with cavity wall insulation and two out of 24 dwellings without wall insulation experienced significant periods of >30°C temperatures. Of the modern houses in the BPE studies, only one, C7-H02, maintains temperatures close to the CIBSE requirement. *Note that the dwellings in C7 were unique in that they are constructed of heavy-weight hempcrete, whereas the other BPE dwellings are light weight timber construction.* Results for overheating assessment using the adaptive method indicates that far fewer houses are judged to overheat under these criteria, six out of the 34 with cavity wall insulation and three out of the 24 with no insulation. Similarly, fewer instances of overheating were found using the adaptive vs. static method in Gupta and Gregg (2017). In contrast to bedrooms there are considerably lower levels of overheating in the living rooms, indicated by the fact that only two houses, C4-H02 and C8-H01 were judged to experience any significant proportion of the summer period >30°C and only a further two, C1-H03 and C8-H02 had periods >28°C. There is also a similar lower level of overheating according to the adaptive method, with an identical list of dwellings being identified in the cavity wall insulation category plus only one in C4-H04 in the uninsulated category.

Adaptive overheating analysis by dwelling characteristics

For dwelling types, the variation across built form is comparatively small, apart from a small sample of flats (n=2) where overheating durations are at least twice to four times the others. For the house types, the variations do not entirely reflect that expected from the differences in exposed outside walls. Mid-terrace houses, with the least exposed area have, as might be expected, the highest degree of overheating in as far as bedrooms are concerned. However, semi-detached houses, which would have been expected to have similar characteristics to end-terraces, are much warmer in bedrooms, but similar in living rooms; and end-terraces have the lowest values of all, at 25% of the semi-detached values. For dwelling age analysis, the most obvious group suffering from comparatively higher levels of overheating are those built between 1981 and 1990, where bedrooms exhibit twice the overheating as the next highest group and where living rooms are also significantly affected. The new-builds have highest level of overheating in living rooms.

The results of the insulation analysis show the insulated dwellings experience overheating approximately twice as frequently as those without; more dwellings with a percentage of occupied hours above comfort temperatures by the adaptive method (Figure 1). The analysis also considered whether the insulation was included in the house as-built or was the subject of a subsequent improvement, either before or after 2008 (pre-2008 insulation standards were lower). Again, dwellings with the highest standard of insulation installed as part of the build, post-2008, were assessed as experiencing the highest level of overheating and those with no insulation as the lowest. The results of the analysis by UK region show little connection between the relative warmth of the 2013 summer and that of the 20-year average, since the dwellings in Wales, where 55.8% higher CDDs were experienced, were almost entirely devoid of overheating and the highest degree of overheating was experienced in London where the actual CDD showed little difference from the 20-year average.

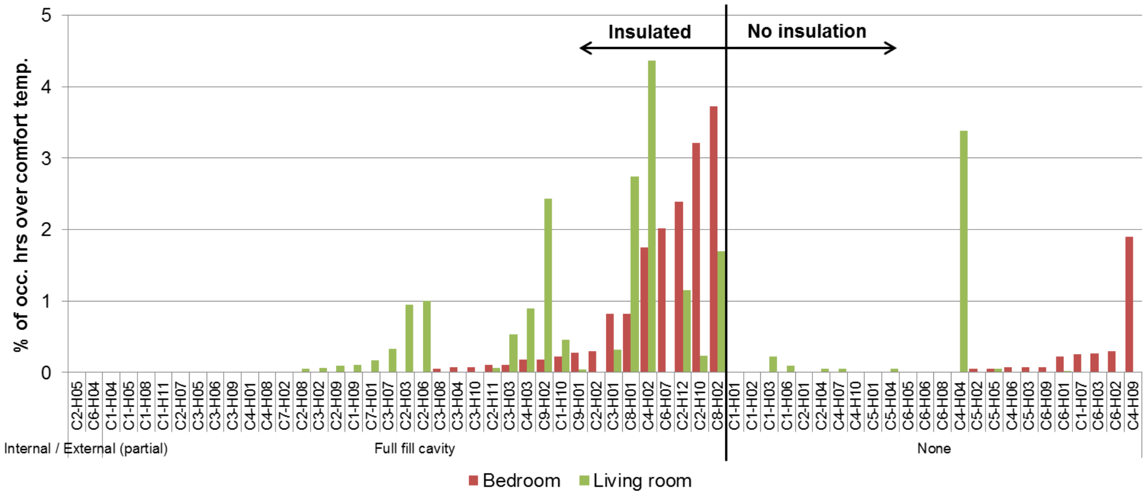

Figure 1. Percentage of hours over comfort temperature (EN BS 15251) by wall insulation. *Note: dwellings are ordered by lowest to highest percentage for bedrooms in each category.*

DISCUSSION

Of the 63 dwellings, only two were found to have bedrooms not exceeding the recommended temperature of 26°C and 17 (27%) were found to have bedrooms exceeded 30°C. Conversely, only three (4.7%) of the living rooms exceeded 30°C, and 22 (34%) had temperatures less than 26°C. In addition, considerably higher temperatures were found in bedrooms than in living rooms. There are wide variations in temperatures between bedrooms and living rooms even in the same dwelling. Overall, it was found that about 74% (42) of bedrooms had higher maximum temperatures than the living room, with this variation being about 1.5°C, whilst, across the remaining 26% (15), the difference was about 0.5°C. It is considered that the higher bedroom temperatures are attributable to the greater exposure to solar irradiance than living rooms since these are largely located at ground floor level rather than bedrooms which are located on the first floor. Given these findings it is important to consider for new-build and retrofit opportunities that bedrooms are equipped to adaptively cool the space, e.g. daytime shading devices designed for seasonal use.

Dwellings with insulated walls appear more prone to overheating than those without, particularly those built to the most modern specifications. However, it would appear that this tendency is moderated in high thermal mass dwellings such as C7-H01 and C7-H02. The coupling of high thermal mass and progressive insulation standards would benefit from further research as a potential solution to this apparent problem which is projected to be more problematic as the climate changes.

The adaptive method assessed far fewer rooms in the dwellings as overheating compared with the fixed temperature criteria of the static method. It could be argued from these results that the adaptive method adjusts better to changes in external temperature since it will adjust the assessment of overheating to correspond to the occupants' perception. However, it is important to note that the adaptive method was designed within the non-domestic context and would benefit from a domestic counterpart as there is currently no dynamic overheating assessment method designed specifically for UK dwellings.

A *domestic* overheating method will need to be tested in all dwellings types, forms and ages since it is likely that any methods used to assess overheating will, in the future, be incorporated into UK government policy and, hence regulations affecting the design of and provision of cooling systems in, social housing, the efficacy of such methods are economically significant. If the required method over-estimates overheating and causes excessive rates of cooling system installation, this will lead to increase in initial building costs and, once such equipment is installed, it will inevitably be used, resulting in increased energy use (and costs) for cooling. If overheating is simultaneously associated with high levels of insulation, then this may lead to a reduction in insulation levels, resulting in excessive energy use for space heating. Conversely, if the method employed underestimates the extent of overheating, this is likely to result in higher levels of health problems, particularly for the elderly, with consequent cost increases for the health services, as well as the distress for the occupants.

CONCLUSION

This study, based on data collected during the summer of 2013 in nine different locations across the UK assessed the prevalence of summertime overheating in bedrooms and living rooms in existing, retrofitted and new-build dwellings. The overheating levels in the dwellings, which were all deemed to be ‘free-running’, i.e. unheated during the period, were assessed using both static and adaptive thermal comfort criteria. Examined from the point of view of the occupants’ health, the significance of the accurate assessment of overheating in dwellings is fairly obvious. However, its significance for the policy and practice of designing new, low-energy homes and energy-efficiency retrofit measures is more subtle. Inaccurate assessment of overheating may leave occupants with houses that are uninhabitable during the hotter days of the year, if underestimated, but if overestimated may cause the installation of many unnecessary air-conditioning units. Moreover, if the causes of overheating were to be wrongly attributed, for example, to high levels of insulation, then many opportunities for energy saving in the heating season might be lost through under-insulation. This is particularly relevant for UK social housing where standards are more rigorously applied.

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