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Summertime Temperatures & Overheating Risk: Does orientation affect comfort in bedrooms in the UK context?

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Abstract
This paper investigates the extent to which orientation affects the internal temperatures and thermal comfort of occupants during summertime. Four, differently oriented, bedroom temperatures were recorded in two modern houses located in Dunblane, Scotland, from 13/6 to 10/7, 2013. Data was also collected by interviewing the occupants. Data retrieved from sensors helped for a direct comparison of temperatures recorded in bedrooms. Thermal comfort was then assessed by using, recommended from CIBSE, static criteria for overheating along with the BSEN15251 adaptive thermal comfort benchmarks. The analysis shows inconsistency between thermal comfort as defined by current standards and the actual thermal sensation of occupants and highlights the complexity of thermal comfort assessment due to the differing levels of personal comfort. Although slight differences were observed on temperatures of bedrooms, in fact orientation does not form a critical factor affecting thermal comfort of occupants.
Keywords: Summer temperatures, Overheating, Thermal Comfort, Orientation, Bedrooms

1. Introduction
The effects of climate change on the internal environment are of rising interest. Climate change projections indicate that Southern England will get warmer by 4 °C and Northern Scotland about 2.5 °C by the 2080s (UKCP09, 2009) with more intense and frequent heat waves, along with drier summers and warmer, wetter winters. The impacts of recent heat waves have caused heat-related deaths which resulted not only from unexpected high temperatures but also from a failure of buildings to amend the external changes. Energy efficiency guidelines focus more on reducing the heating demands and have led the design of dwellings' majority towards a more lightweight and airtight construction that maximizes heat gains and reduces heat loses. Although beneficial for winter, occupants risk experiencing discomfort due to elevated internal temperatures during summer. The impact of climate change in indoor temperatures of dwellings has been the focus of many studies. A common finding is that, new build houses is the type of dwelling more prone to the risk of overheating with bedrooms being warmer than living rooms.

2. Overheating and Thermal Comfort
Although the term "overheating" is widely used, at present there is no precise definition. Overheating can be said to occur when the indoor temperature rises beyond the upper limit of the comfort temperature band for that day by enough to make people feel uncomfortably hot (CIBSE, 2010). Obviously, overheating is strongly related with thermal comfort which, according to the generally accepted definition of ASHRAE, is "*that state of mind which expresses satisfaction with the thermal environment*". Our thermal interactions with the environment are expressed with our behaviour and with actions that we take in order to regulate our thermal sensation and feel comfortable. This is incorporated into the adaptive approach which is based on

the Adaptive Principle (Nicol et al, 2012): "*If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort*". Adaptive thermal comfort is actually a function of the possibilities of change, as well as the temperatures achieved (Nicol and Humphreys, 2002).

3. Overheating criteria and Adaptive Thermal Comfort Standards

There are number of overheating criteria some of which are based on comfort prediction while other on the number of hours for which a particular temperature is exceeded (static criteria).

European standard EN15251 (BSI, 2008) is the most relevant standard for UK dwellings as it suggests indoor temperatures (Figure 3.1) valid for offices and building types where occupants have easy access to windows, are free to adapt their clothing and their main activity is sedentary. It is the most appropriate for this study as it "*specifies methods for long term evaluation of the indoor environment obtained as a result of calculations or measurements*". The standard to be used for evaluating naturally ventilated buildings is following the adaptive approach as well as the equation relating comfort temperature to outdoor temperature (T_{rm}): $T_{comf} = 0.33 \cdot T_{rm} + 18.8$. BSEN15251 uses categories for buildings defined by the type of the building and its use. The category I thresholds represent a high level of thermal expectations (addressed to very sensitive or fragile persons), Cat II are for normal level of expectation and Cat III thresholds are for acceptable moderate expectation and can be used in existing buildings. Cat IV values lie outside the above criteria and should be used only for limited periods. BSEN 15251 offers different methods of defining the level of thermal discomfort. The easiest is to calculate the percentage of occupied hours for which the temperature exceeds the threshold of interest. It is recommended that the acceptable limit is 5% of hours in any day, week, month or year.

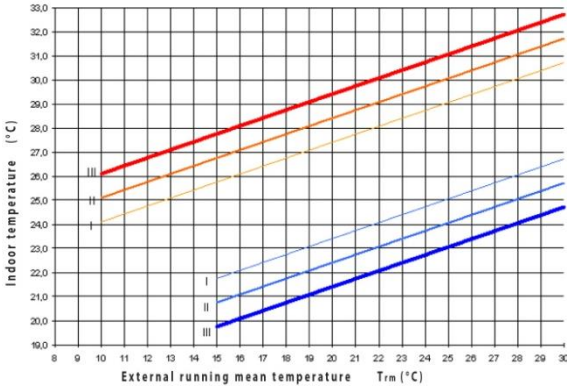

Figure 3.1: European Standard 15251 category thresholds, (BSI, 2008)

Static criteria, such as those demonstrated by **CIBSE Guide A** (2006) use fixed threshold temperatures that neither take into account external conditions nor temperature influenced by building occupant behaviour. The guide suggests that "*summer thermal performance should be measured against a benchmark temperature that should not be exceeded for a designated numbers of hours or a percentage of the annual occupied hours*". Concerning bedrooms, the guide indicates that "*thermal comfort and quality of sleep begin to decrease if bedroom temperatures rise much above 24°C*" and that "*bedroom temperatures at night should not exceed 26°C unless ceiling fans are available*".

4. Building Monitoring: Measurement and Recording

4.1 Criteria for selection

This study presents an analysis of the internal temperatures recorded in four bedrooms of two modern houses located in Dunblane of Scotland, a small town north-west of Edinburgh and north of Stirling, with a population of 7,911 at the 2001 census. "House A" is directed towards East-West and occupied by a couple. "House B" faces South-North, occupied by a working couple with their young daughter. Both houses

are detached, have the same construction -timber frame with insulation in roof-, same location (same street) but whilst one (House A) has bedrooms facing East-West, the other (House B) faces South-North. Neither of the houses have any external shading device for the windows; however, all of them have internal curtains or blinds.

4.2 Research Methodology

4.2.1 Quantitative Method

Six "Tinytag" sensors were used to measure temperature and humidity and store the data until downloaded. The sensors recorded external temperatures along with internal temperatures in four bedrooms at 5 min intervals from 13th of June to 10th of July 2013. In order to record the window opening, a small sheet was given to occupants in order to indicate when they open the window and the reason for doing so.

4.2.2 Qualitative Method

The study also aims to understand the occupants' thermal sensation and relate it to the measured data. Questionnaires provided information about occupancy patterns, window opening habits, occupants' thermal sensation during the day, their thermal preference as well as their general perception about overheating.

5 Findings

5.1 External Conditions

The temperatures from 13 June to 10 of July are the focus of this study. During this period, the external temperature varied from 6.5 °C to a peak of 31.7 °C. Apart from two days, that were unusually cold (with peak temperatures 12.4 °C and 14.9 °C respectively), most of the days had daily temperatures ranging from about 11 °C to approximately 20 °C to 22 °C. The warmest day was the 8th of July, when the temperature ranged from 14.7 °C to a peak of 31.7 °C.

5.2 Quantitative Findings

The analysis is divided into two stages: the first is to understand the thermal behaviour of bedrooms with different orientation and the second is to assess thermal comfort given the recorded temperatures. Two different methods of comparison between the four bedrooms are used in order to identify which of them appears to be the warmest. The two methods are:

Method A: Percentage of hours over 24 °C & 26 °C for the whole monitoring period.

Method B: Comparison of temperatures recorded during individual days selected under criteria such as: hottest day, sunny day, overcast day, day with windows closed.

In the second stage, we are going to focus more on occupied hours in order to assess thermal comfort under European Standard BSEN 15251 (BSI, 2008) and finally use CIBSE (2006) overheating criteria to identify whether an overheating risk occurs.

5.2.1 Thermal performance of bedrooms

Method A: Hours over 24 & 26 °C

As illustrated in Fig. 5.1, bedrooms facing South and West have the highest percentage of temperatures over 24°C with 9.9% and 9.4% respectively, followed by North with 9.1%. Surprisingly, the highest percentage of temperatures over 26 °C were reported in North bedroom with a

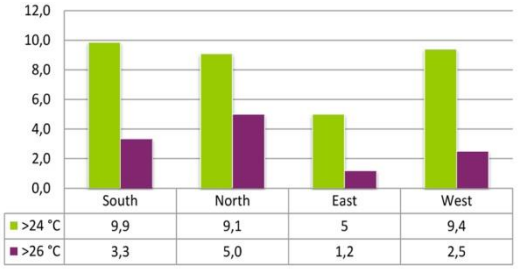

Figure 5.1: Percentage of hours above 24 & 26 °C

percentage of 5% followed by South with 3.3%. Similarly to the previous method, the results show that South, North and West bedroom can be equally warm. Finally, this chart indicates that South and North might be more prone to the risk of overheating.

Method B: Combining data for hottest, sunny, overcast, & day with windows closed

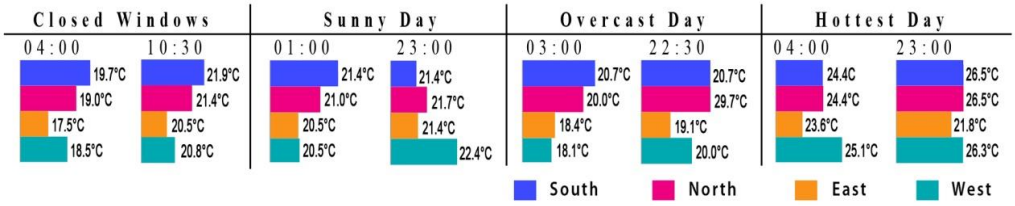

Figure 5.2: Charts showing temperatures for particular days and times

A number of combining data were produced based on the original graphs downloaded by the gauges. The diagrams of all the bedrooms during a particular day have been put together in a graph so that it is easier to compare. For economy of space, charts showing the temperature recorded for particular times of the occupied hours (22:00 – 06:00) are presented in this paper.

The analysis revealed that temperatures do not differ to a great extent among the bedrooms. As expected, South and West (Fig. 5.2) tend to be warmer during the night time; however, North bedroom had often similar temperatures to South. This might be due to the fact that occupants leave the doors open so air can move between these two rooms. Another reason might be the sunlight falling into North windows due to the low angle of the sun during sunrise and sunset in latitude of 56°N. Similarly to night time, South and West appeared to be the warmest rooms during the day, followed by North and finally East bedroom. According to these findings, orientation seems determinant in thermal behaviour of bedrooms but this can change by occupants' actions.

5.2.2 Thermal comfort assessment

5.2.2.1 Assessment using static criteria

Analysis using the CIBSE criteria was only contacted for the three warmest days (Fig. 5.3) of the monitoring period and show that during warm external conditions bedrooms tend to have elevated temperatures that exceed the "5% over 24 °C" criterion. The overheating criterion of "1% over 26 °C" was only exceeded on 9th of July in South, North and East bedrooms, showing that it is likely for bedrooms to overheat if they are exposed in a longer period of warm temperatures. Although South seems to be the warmest, the criteria gave the impression that all monitored rooms are likely to have temperatures that could be deemed as "uncomfortably warm" in the case of high external temperatures.

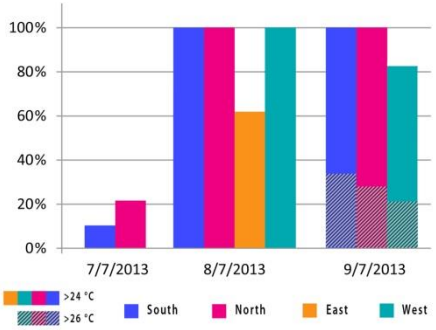

Figure 5.3: Percentage of occupied hours (22:00-06:00) for all four bedrooms for which air temperature exceeded 24 & 26 °C

The CIBSE thresholds are used to identify the bedrooms that are more prone to elevated temperatures. As these are applied to a small measurement period and not a whole year, values exceeding 1% and 5% do not indicate overheating as defined by CIBSE

5.2.2.2 Assessment using adaptive thermal comfort criteria

To assess the internal temperatures during occupied hours using the BSEN15251 adaptive standard, the hourly temperatures were plotted against the running mean of the daily average external temperature (T_{rm}), for all bedrooms. The plots illustrate the various temperatures found in all four rooms for particular days. In contrast to CIBSE

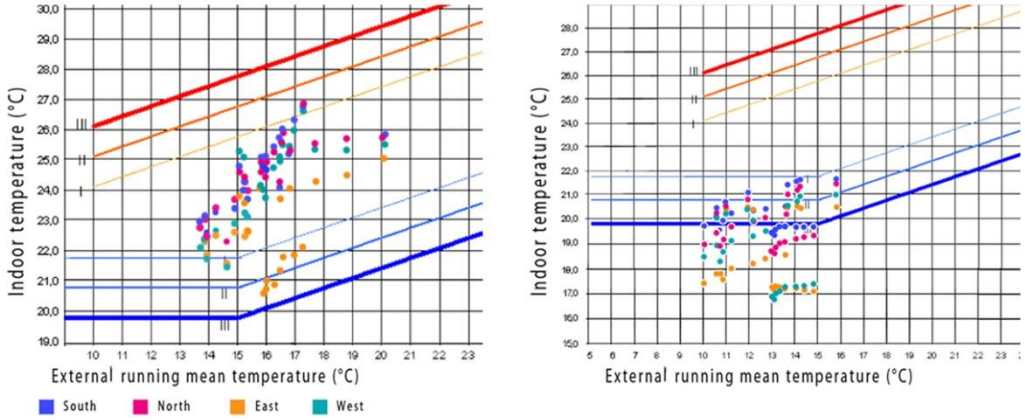

Figure 5.4 & 5.5: BSEN15251 thresholds and the hourly temperatures measured during the three warmest days (left) and during an overcast, a sunny and a day with closed windows (right)

recommendations, analysis using the BSEN15251 criteria, show that internal conditions were mainly among the comfort thresholds with no indication of temperatures being warm (Fig 5.4 & 5.5). The majority of temperatures are within the Cat I boundaries apart from the East bedroom that had temperatures below Cat II which is suggested as normal level of expectation. Concerning the rest of monitoring period, even when the external temperatures are not very low there is a general tendency for cool, rather than warm, temperatures (Fig 5.5); temperatures that in some cases, according to the Standard are uncomfortable. In some cases, the acceptable limit of 5% of hours below Cat III threshold, as defined by BSEN15251, is exceeded for all bedrooms.

5.3 Qualitative Findings

Information obtained from questionnaires show clear indications of people feeling warm in their bedrooms while problems such as feeling hot or poor quality of sleep might occur only in cases of unusual hot summer days. Two are the most interesting findings from the qualitative survey; the variation in the thermal perception between the occupants of the same room and the fact that even in the case of warm temperatures, it is not certain that all occupants would prefer them to be lower. This proves that comfort differs from person to person and depends on numerous parameters such as clothing and metabolic rate. Thermal comfort is also a matter of preference; some might find warm conditions ideal for sleeping while others might prefer a slightly cooler environment. Finally, the responses between the two couples did not vary significantly (Table 1), making it difficult to identify which room is considered as the warmest by the occupants

SOUTH / EAST	Thermal Sensation		Thermal Preference	
	Morning	Night	Morning	Night
S. Male	0	+3	higher	no change
S. Female	+2	+1	lower	lower
E. Male	+2	+3	no change	lower
E. Female	0	+1	no change	no change

Table 1: Table summarizing occupant responses on thermal sensation and thermal preference. 0,+1,+2,+3 is for neutral, slightly warm, warm and hot respectively.

6. Comparison between qualitative – quantitative results

It is interesting to compare the quantitative results with the information obtained from the qualitative analysis. Although South and East bedrooms are defined as the warmest and coldest among the monitored rooms, occupants' responses do not reflect such a difference as they experience "warm" and "hot" temperatures in both South and East bedrooms. Moreover, occupants' perception of thermal comfort does not fully conform to the results obtained by the analysis using adaptive criteria for thermal comfort. Instead, occupants' responses clearly show that their thermal sensation ranges from "neutral", which means comfortable, to "hot". Eventually, occupants feel satisfied with low internal temperatures as defined by the BSEN15251 thermal comfort standard. This is because, the BSEN15251 method has been derived using data from, and to assess thermal comfort in offices. However, people operate quite differently at home which is an environment that offers plentiful adaptive opportunities. These opportunities enable temperatures being under Cat III threshold to be considered as comfortable.

7. Conclusions

This study investigated the thermal behaviour and thermal comfort in bedrooms of different orientation. The analysis show that, orientation does play a role in determining the internal temperature of bedrooms, however, this is subject to change due to actions taken by occupants (e.g. open windows). Even though temperature differences observed between bedrooms with regard to their orientation (especially between South and East), the study revealed that, regardless of their orientation, all of the tested bedrooms are likely to experience temperatures considered as "uncomfortably warm". Eventually, we could conclude that, although orientation affects internal temperatures, it does not form a critical factor for the thermal comfort of occupants.

Inconsistency found between thermal comfort as defined by current standards and the actual thermal sensation of occupants highlighted the complexity in assessing thermal comfort. This indicates the need for new thresholds that consider the variation in occupants' perception and are more suitable in assessing thermal comfort in dwellings. Finally, the fact that occupants have experienced warm conditions during extreme hot summer days indicates that the scale of the problem might become larger in the future, when this phenomenon is predicted to be more usual.

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