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Investigating the impact of thermal history on indoor environmental preferences in a modern halls of residence complex

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Abstract

Numerous field studies conducted in different locations have demonstrated that comfort conditions vary due to adaptation to the local climate. This study aims to investigate how preferences for the indoor environment change when the climate context changes and how thermal history influences comfort conditions in a new thermal environment. A new halls of residence complex in the south of England, housing occupants from various climatic regions, is used as a case study. Two thermal comfort surveys were conducted in October and December 2015 (N=53 residents) within the first three months of the occupants. Air temperature and relative humidity measurements were collected during this period.

Results show a range of comfort temperatures of over 10^{o}C across the study period. The first survey (October) found no significant difference between residents when grouped by previous climate of residence. The second survey (December) found that the mean comfort temperature for residents from the UK had dropped by 1^{o}C, despite an unseasonably warm winter, and mean comfort temperatures for residents from other climates remained the same. This could be an indication of psychological adaptation whereby residents accustomed to the UK climate expect cooler temperatures moving from October to December and thus come to prefer this.

1 Introduction

With increasing focus on reducing carbon emissions to mitigate climate change impacts and meet the UK's 2050 emissions reduction target of 80% of the 1990 level (Crown Copyright 2008), energy efficiency measures are being addressed in a number of sectors. In the UK, domestic space heating alone accounted for 23% of total energy demand in 2011 (DECC 2013). While the technology to build highly efficient, low energy homes already exists, the challenge for designers is to provide functional and comfortable dwellings while maintaining low energy use. The difficulty lies in characterising occupant behaviour in the design stage which has been found to impact significantly on energy performance (Bonte et al. 2014; Gill et al. 2010; Martinaitis et al. 2015) and occupant satisfaction (Grandclément et al. 2014).

At present, occupants are usually assumed to be a homogenous population with similar thermal preferences. The recommended design temperature ranges in regulations and standards are based on studies carried out mainly in temperate climates (ISO 2005; CEN 2007). While this may be appropriate in the situation where all occupants under consideration are long term residents of the region, it becomes questionable when considering occupants from mixed climatic backgrounds. Many field studies have been conducted in various climates across the world which serve to demonstrate that comfort temperature is closely linked to local climate and to indoor temperature variation which is influenced by ventilation strategy (Rupp et al. 2015; Kwong et al. 2014; Taleghani et al. 2013; Brager & de Dear 1998). These studies have demonstrated that occupants of naturally ventilated buildings in hot climates can be comfortable at temperatures far higher than expected by deterministic models of comfort, sometimes exceeding 30^{o}C (Djamila et al. 2013; Dhaka et al. 2013). Similarly, some studies have found the reverse, that occupants in cold climates can adapt to find comfort in low indoor temperatures (Ye et al. 2006; Yu et al. 2013; Luo et al. 2016).

Adaptive thermal comfort theory explains these variations in comfort temperature by asserting that over time, people are able to adapt to their climate through a combination of behavioural, physiological and psychological mechanisms (Nicol et al. 2012; de Dear & Brager 1998). Behavioural adaptation, linked to personal control, has been found to lead to diverse thermal preference (Brager et al. 2004; Luo et al. 2014) and in a number of cases this has been linked to energy performance implications both with respect to heating and cooling (Luo et al. 2015; Zhang et al. 2013; Zhang et al. 2010). Physiological adaptation or acclimatisation refers to changes in thermoregulatory mechanisms, such as sweating and vasodilation, which allow people accustomed to a particular climate to deal with exposure to that climate more effectively. While it is often considered to be less significant in explaining moderate changes in climate than behavioural and psychological adaptation (de Dear & Brager 1998), studies have suggested evidence for this (Lee et al. 2010; Yu et al. 2012). Finally, psychological adaptation is often hard to distinguish as a factor as the process and its impacts are hard to characterise. However, it has been postulated that expectations of how environments should be, based on experience, influences how people experience them (Humphreys & Nicol 1998)

This study aims to investigate how these adaptive processes change when considered in the context of a new climate. That is to say, the impact of individuals moving, with all their existing adaptations and thermal history developed in their 'home' climate, to a new climate where indoor environments are designed for residents with a different set of adaptations.

2 Methodology

This study employed a mixed methods approach utilising environmental monitoring, subjective questionnaires and data from a local weather station in a halls of residence complex. The case study is the University of Southampton's newly constructed Mayflower Halls of Residence located in the city centre of Southampton, UK. First occupied in October 2014, the complex provides 1104 naturally ventilated accommodation rooms most of which are single ensuite rooms arranged in cluster flats with shared kitchen/living room, although some studio and 1-bedroom flats are also available. This is considered a suitable case study as it houses a large number of international students who are likely to be of a similar age.

Figure 1 Mayflower Halls of residence facades. Top left: North-East facade, right: South-East facade, bottom left: courtyard and internal East and North West facades

Figure 3 shows schematic plans of typical accommodation units in Mayflower Halls. Each resident has access to controls enabling them to, in principle, maintain their indoor environment to suit their preferences. These include curtains, top opening tilt windows with trickle vents (Figure 2; left) and individual radiator valves with settings 0 to 5, where is 0 is off and 5 the highest setting (Figure 2;right).

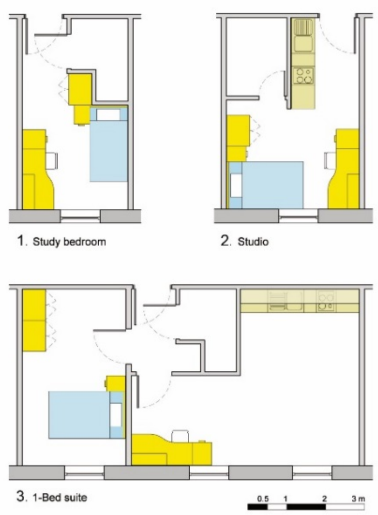

Figure 3 Schematic plans showing typical layout of accommodation rooms in Mayflower halls of residence

Figure 2 Indoor environmental controls available to Mayflower residents; radiator control valve (left), top opening tilt window with trickle vent (right)

2.1 Sample

Participation was open to all residents with first contact being made by email a few weeks after their one year occupancy began in the last week of September 2015. Since the focus of the study was to investigate the impact of thermal history, the intention was to have one third UK students and two thirds residents who had moved into Mayflower from another climate. Non-UK participants are those who stated that for the two years prior to moving to Mayflower, they had "…mostly been living in X…" where X was not the UK. The final sample employed for the study consisted of 56 residents, however this reduced to 53 later in the study period following three withdrawals.

In order to investigate differences in thermal preference between occupants already adapted to the UK climate and those who are not, a method to categorise climate history was introduced. Category A (cool/cold) climates are those where the mean temperature of the coldest month is equal to or lower than that of the coldest month in Southampton (4.6^{o}C); this group is further divided into UK and NON-UK in order to identify occupants from climates which may have colder winters than southern England. The mean temperature of Southampton was used (as opposed the UK) as temperature can vary quite significantly between the north and south of the country (965km) and since all the residents in the sample from the UK are from southern regions, Southampton was taken to be a representative location. Category B (warm/hot) climate are those where the mean temperature of the coldest month is higher than that of the coldest month in Southampton. This classification is used throughout the paper.

2.2 Environmental monitoring

Air temperature and relative humidity were monitored in all participants' rooms starting in late October 2015 (a few weeks after residents had moved into the case study). This was done using MadgeTech RHTemp101A data loggers which provide measurement resolution of 0.01^{o}C and 0.1% humidity for temperature and relative humidity, respectively. The selected reading rate for this investigation was 5 minutes, as this allowed a detailed picture of temperature variation in the accommodation rooms. One data logger was placed in each of the investigated rooms. The locations of the data loggers were selected so as to avoid direct solar radiation or proximity to other heating sources.

2.3 Thermal comfort surveys

Thermal comfort surveys were carried out in the participants' rooms. Indoor environmental measurements of air temperature, relative humidity, globe temperature and air velocity were taken during the face to face questionnaire using the portable DeltaOhm HD32.3 instrument. The questionnaire included questions about general perception of environmental conditions (including temperature and air movement), frequency of controls use and details about location of previous residence, including details of space heating and cooling facilities and ventilation strategy. For the assessment of thermal comfort at the time of the questionnaire, the 7-point ASHRAE thermal sensation scale was used (ASHRAE 2013) with 5-point thermal preference scale. Also recorded were clothing levels and reported activity level for the 30 minutes prior to the questionnaire.

Two sets of survey data are used in this analysis, both from the 2015/2016 academic year and both conducted over the first three months of the occupants one year stay (October 2015 – December 2015). The first of the two questionnaires was carried out over a fifteen day period at the end of October 2015 and the second over a fifteen day period in early

December 2015. This allowed investigation of participants change in comfort temperature over time which can be considered to be evidence of adaptation.

3 Results & Discussion

3.1 Factors which could affect occupants' comfort temperature

The aim of this paper is to investigate the impact that thermal history has on comfort temperature in a new climate. However, to do this requires first that other factors that are known to impact comfort temperature and indoor climate are considered. Factors to be considered here are gender, age and building characteristics. Gender is also often considered important in understanding indoor environmental preferences (Karjalainen 2007; Wang 2006) however a previous study conducted in this building, using similar methods found it to be negligible and thus is not considered here in further detail (Amin et al. 2015).

The age distribution, shown in Figure 4, highlights a cluster of participants around the age of 18-19 (first year undergraduates) and again 22-25 (Masters). Thus, while we can see some variation in age and a few outlying values this is not deemed to be influential due to both the small number of outlying values and relatively small range in ages amongst the majority of the sample. Indeed some studies considering the effects of age on comfort typically consider groups of at least 10 years in range (Indraganti & Rao 2010) and in some cases greater, e.g. over 65 years and under 65 years (Del Ferraro et al. 2015).

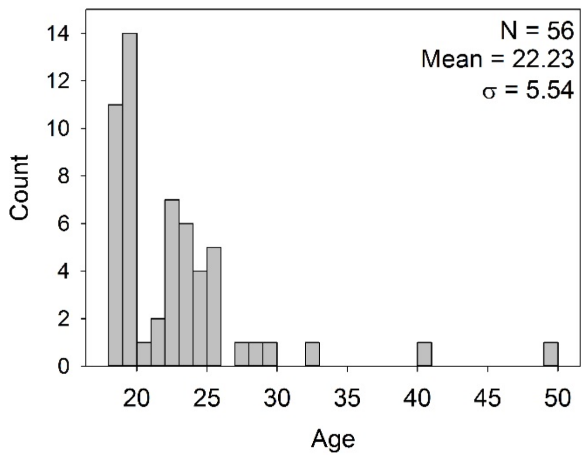

Figure 4 Histogram showing age distribution of study sample

Finally, considering building characteristics is key to understanding both user satisfaction and the indoor environment as they can have a strong influence on both of these factors. In some cases this could include building fabric but since all participants of this study are residents of the same building complex, this is negligible. In this instance, it is likely that floor level and orientation are likely to have the strongest influence on indoor temperature as the complex is split over 16 floors and the orientations of the rooms allow for vastly different levels of solar gain. Hence, rooms were clustered by orientation and floor level such that all rooms in a cluster are within three floor levels and on the same façade (within 6 rooms along) as each other. Plotting the mean monitored indoor temperature of two weeks at the end of November by cluster (Figure 5) shows the diversity in indoor temperature in rooms which cannot be explained by orientation and floor level alone; in one case (Cluster 1) a difference of over 6°C. This period was chosen as it is during the heating season where occupants' are likely to have greater control to create the preferred indoor environment. This further serves to highlight both the diversity in thermal preference and that occupant behaviour is likely to be a determinant for indoor temperature.

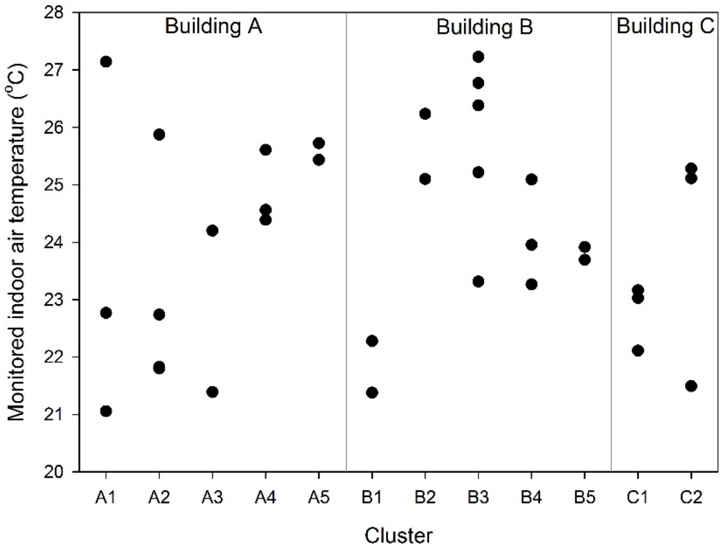

Figure 5 Mean monitored indoor air temperature for two week before second comfort survey (December 2015) clustered by orientation and floor level so that all rooms in a cluster are within 3 floor levels and on the same facade (within 6 rooms) as each other. Clusters are grouped by building (A, B, C – see Figure 1) where lower numbered clusters refer (approximately) to lower floor numbers.

Another interesting finding from the face-to-face questionnaire which is likely to have a strong influence in understanding the building occupants moving forward is that the range in number of hours spent in their accommodation rooms (including sleeping time) varies greatly; from 10-20 hours on weekdays and 0-22 hours on weekends. In terms of understanding the occupants from their monitored data this is likely to be of great importance in one of two ways. Either, those who spend longer in their rooms are likely to be controlling their environment to suit their preferences for much longer than their counterparts who spend fewer hours in the rooms. Alternatively, those who spend a greater number of hours in their room may adapt to their indoor environment and thus feel less of a need to take actions to modify it. In either case, monitored data from some rooms is likely to provide a more accurate picture of the occupant's preference than others.

3.2 General thermal sensation and preference

Thermal comfort surveys began shortly after the start of the 2015 Academic year in October with the first questionnaire and data logger installation taking place between 19th October and 3rd November 2015 and the second questionnaire from 30th November and 14th December 2015. The sample consisted of 56 participants, 23 males and 33 females which later reduced to 53. Figure 6 shows the distribution of thermal sensation votes and thermal preference votes across the two surveys. The thermal sensation vote (TSV) provides the participants current perception of temperature (on a 7-point scale) and the thermal preference vote (TPV) indicates their inclination to change their environment if they were able to. Figure 6 highlights a slight shift between the two surveys moving into the heating season where there is a noticeable decrease in people reporting 'neutral' or 0. This change comes despite the fact that the range in indoor temperatures were similar during both surveys, 20.8°C and 27.3°C in October and 19.4°C and 27.4°C implying that some adaptation has taken place such that expectation of the environment has changed. Furthermore, there is evidence for a change in desire to modify their environments for the cooler. For example, in the case of TSV=+1, the number of people casting this vote is the same in both surveys but there appear to be less inclination to prefer cooler in the second survey. This is also reflected in TSV=+2 where there is no longer a participant preferring 'much cooler'.

The fact that the range of mean globe temperature recorded during the face-to-face questionnaire was between 20.8°C and 27.3°C in October and 19.4°C and 27.4°C in December serves to highlight the diversity in comfort temperatures experienced by residents as in both cases the majority found the environment satisfactory (-1 ≤TSV≤1).

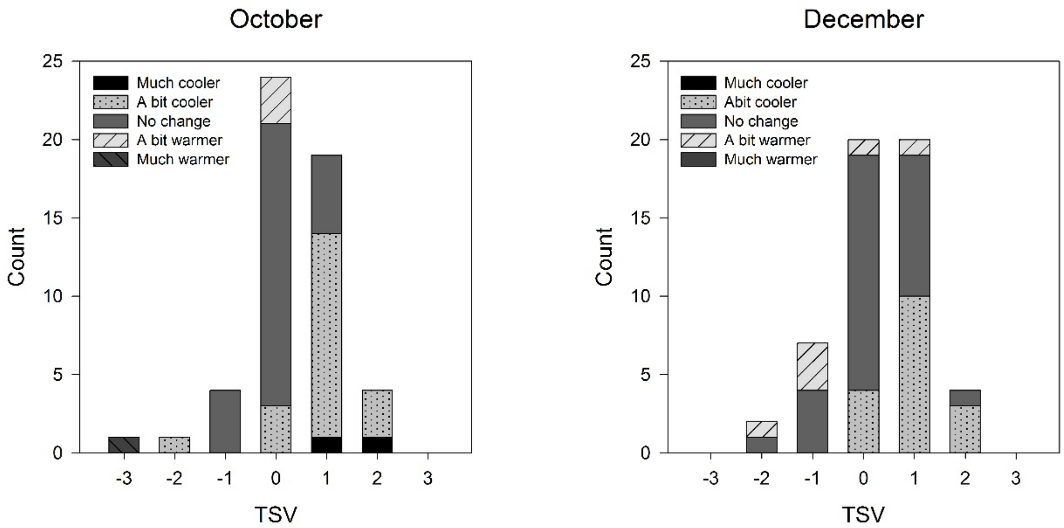

Figure 6 Histogram showing the distribution of Thermal Sensation Votes (TSV) in the October and December thermal comfort surveys along with proportion of thermal preference votes

3.3 Comfort temperatures

Comfort temperatures, T_{com}, were calculated using the Griffiths method which uses the globe (operative) temperature measured during the face-to-face questionnaire along with the thermal sensation vote. The Griffiths constant is taken to be 0.5 (Nicol & Humphreys 2010):

$$T_{com} = T_{op} + \frac{TSV}{0.5} \quad (1)$$

where T_{op} is the operative temperature at the time of the survey and TSV the thermal sensation vote.

The participants were then grouped by climate of previous residence as described in the Methodology (Section 2.1). Of the 56 participants, 23 had been living in the UK for two years prior to moving into Mayflower (Category A – UK), 19 had been in countries other than the UK that have climates as cold as or colder than the UK (Category A – NON UK) and 14 had been living in warm/hot climates (Category B).

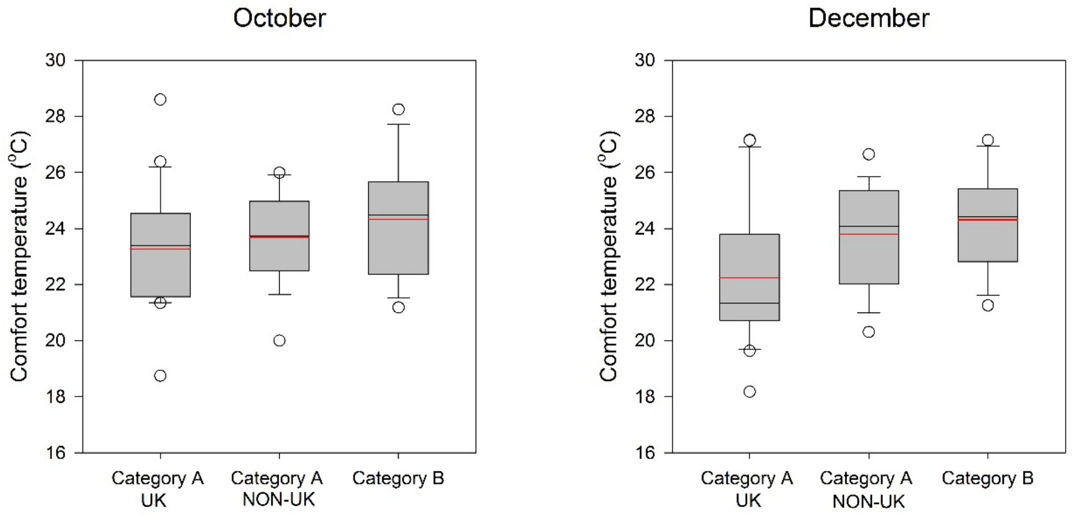

Figure 7 Box plots showing the mean (red line) median (black line), 10th, 25th, 75th, 90th percentiles and outliers (circles) of comfort temperature calculated in October where n=56 (left) and December where n=53 (right). Values are grouped by climate of residence two years prior to moving to the case study building.

Figure 7 shows box plots summarising comfort temperatures grouped by climate. The mean outdoor temperature during the October survey (n=56) was 10.6°C (σ=1.7) and during the December survey (n=53) was 10.2°C (σ=2.2). These mean outdoor temperatures are unusual for the UK, with December being 4.1°C higher than the long term average (Met Office 2016). The means and standard deviations of the comfort temperatures for the three groups are shown in

Table 1. As can be seen, the mean comfort temperature of Category B group (warm/hot 'home' climates') is approximately 1°C higher than that of the other two groups. No statistically significant difference was found between groups in the October survey ($p=0.321$). There was a statistically significant difference found between groups in the December survey ($p=0.016$), between Category A-UK and Category A NON-UK ($p<0.05$) and also between Category A-UK and Category B ($p<0.05$). It is possible that there is no statistical difference in mean comfort temperatures in the first survey as all the residents, regardless of their climate history, are adapting to very different living conditions in the halls of residence complex than they are likely to be used to.

Table 1 Summary table showing means and standard deviations of comfort temperature for October, comfort temperature for December and monitored air temperature for December (two weeks before comfort temperature calculation) for the three climate groups

	October T_{com} (°C)		December T_{com} (°C)	
	mean	**σ**	**mean**	**σ**
Category A- UK	23.3	2.2	22.2 [a, b]	2.4
Category A – NON UK	23.7	1.6	23.8 [a]	1.8
Category B	24.3	2.1	24.3 [b]	1.7

a – statistically significant difference Category A-UK and Category A-NON UK, $p<0.05$
b – statistically significant difference Category A-UK and Category B, $p<0.05$

Between the first and second survey there is a decrease in mean comfort temperature in Category A- UK of over 1°C. The other two groups, Category A- NON UK and Category B demonstrate little to no change in mean comfort temperature from one survey to the other. This is illustrated in Figure 8, which shows the comfort temperatures of each participant in the three groups in October and December. While all groups contain individuals whose comfort temperature change (increase or decrease) dramatically (up to 4.5°C) between surveys, it is clear to see that the only groups that displays a change in mean is Category A – UK. This is an interesting finding given that the ambient temperature changed very little over this period, reinforcing the fact that comfort temperature is not only determined by outdoor temperature. Taking this further, the fact that only the residents who have been living in the UK before the start of the study showed a decrease in comfort temperature could be taken as evidence of psychological adaptation. That is, since these residents are accustomed to the seasonality of the UK, they have come to expect colder temperatures and therefore subconsciously prefer them. It is possible that this is driven by other environmental cues such as shorter daylight hours. In Southampton, sunrise typically occurs at 06:28 GMT and sunset at 17:17 GMT in mid-October compared to 08:02 GMT (sunrise) and 16:00 GMT (sunset) in mid-December (HMNAO 2011).

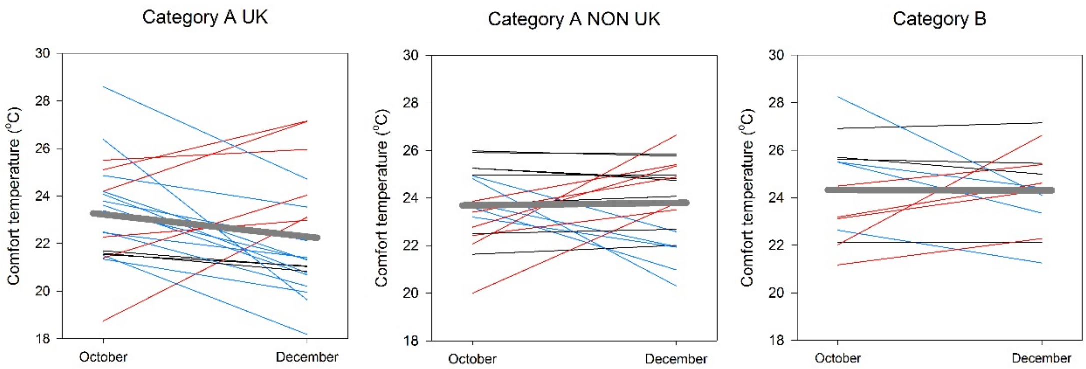

Figure 8 Change in comfort temperature from October to December and monitored indoor temperature in December grouped by climate of residence for 2 years prior to moving to Mayflower halls of residence. Red lines indicates increase in comfort temperature, blue lines indicates decrease in comfort temperature and black lines indicates negligible change in comfort temperature (<0.75°C). Bold grey line indicates change in mean comfort temperature.

Figure 9 shows the daily mean monitored indoor air temperature for the 53 participants who completed both thermal comfort surveys for the period between the two surveys (04/11/15 – 29/11/15) grouped by Category. Also shown is the ambient temperature. Most noticeable is the sharp drop in outdoor temperature on the 22nd November which corresponds to sharp drops in daily mean indoor temperatures in a few rooms which is likely to be a result of windows left open and radiator set on either low or off during this period. Considering that many of the rooms maintain very stable temperatures during this period, it is significant that the rooms with greatest drops in temperature are in Category A-UK, as leaving windows open is behaviour consistent with trying to achieve cooler temperatures. This agrees with the findings of the thermal comfort surveys and implies a move towards cooler temperature in the Category A-UK group and not in the other groups.

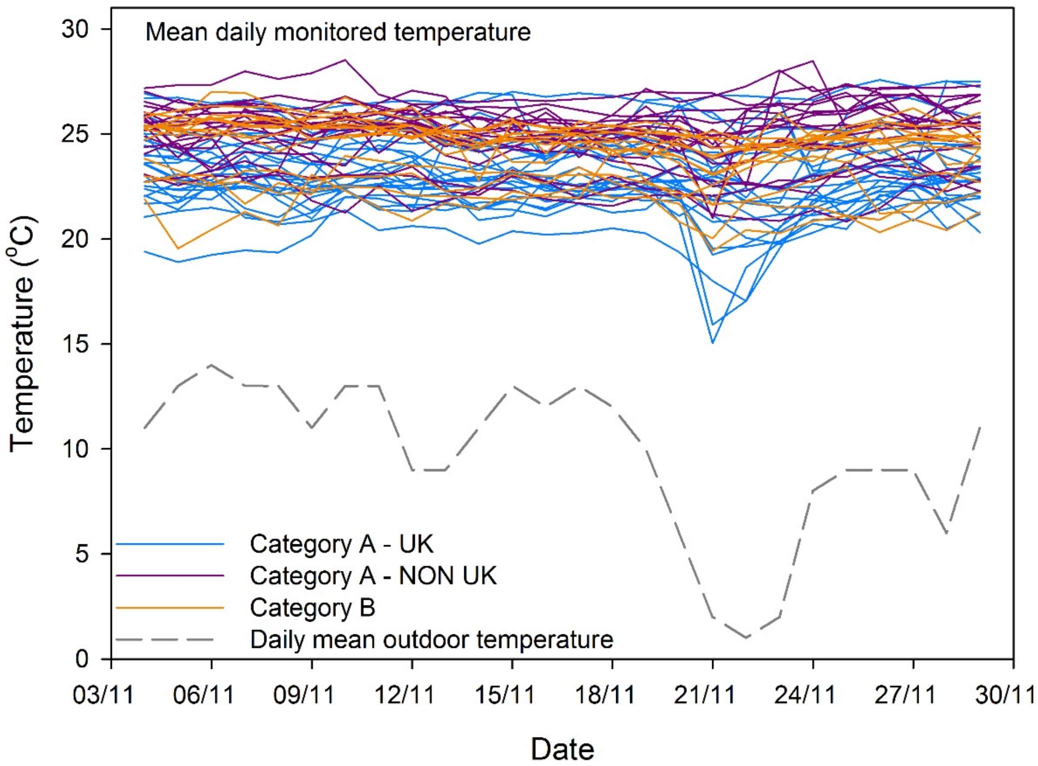

Figure 9 Mean daily monitored air temperature from 53 accommodation rooms in Mayflower Halls for the period between the first and second thermal comfort survey (04/11/15-29/11/15) coloured by climate of residence prior to moving to the case study building

The final relationship considered in this study was the fundamental adaptive relationship of indoor temperature and comfort temperature. Figure 10 shows a scatter plot of mean comfort temperature of the two surveys against mean indoor monitored temperature for the period between the two surveys. The correlation coefficient, r, for all data points was found to be 0.51 ($p<0.05$) however more interesting is the difference in correlation between the 3 categories. The correlation coefficients were found to be 0.69 ($p<0.05$), 0.14 ($p>0.05$) and 0.28 ($p>0.05$) for Category A UK, Category A NON UK and Category B, respectively. There is no significant relationship between comfort temperature and indoor temperature in either Category A NON UK or Category B but there is in Category A. This shows that indoor temperature is a good indicator of comfort temperature in residents who are already adapted to the UK conditions but not for residents who are not. Some of the scatter seen here may be due to the fact that both surveys considered here are early in the occupancy period and residents may still be familiarising themselves with their new environment. Furthermore, the data used to calculate the average indoor temperature included unoccupied periods; if the exact occupancy schedules were known, a stronger relationship may have been observed. However, it is evident that occupants from the UK are better able to control their environment to suit their comfort.

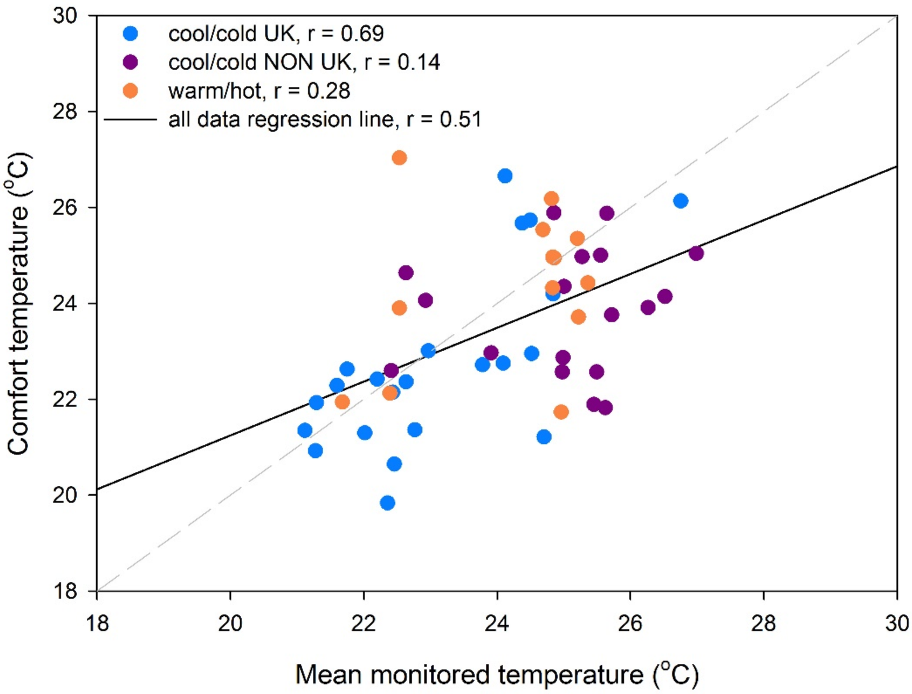

Figure 10 Relationship between comfort temperature and mean indoor temperature. The comfort temperature is the average of the two surveys and the mean monitored temperature is for the period between the two surveys. The solid line shows the regression line for all data values and the correlation coefficients for the individual groups are shown in the legend.

4 Conclusions

This study has investigated thermal preferences of occupants of Mayflower halls of residence complex in Southampton, UK using a mixed methods approach. It has been shown that variation in monitored air temperature cannot be attributed only to orientation and floor level in this case and furthermore that residents have reported feeling neutral (on a 7 point ASHRAE scale) within a wide range of measured globe temperatures. Differences in comfort temperature of over 10°C were found across two thermal comfort surveys conducted in October and December (within the first three months of the occupants stay). The first survey (October) found no statistically significant difference in comfort temperature of occupants when grouped by climate of residence for two years prior to moving to Mayflower, however a significant difference had emerged by the time of the second survey (December). One-way ANOVA revealed a statistically significant difference in comfort temperature between residents from Category A-UK and both Category A-NON UK and Category B, where the mean comfort temperature of the Category A-UK group had decreased by 1°C and the others had remained the same. This arose despite very little change in ambient temperature due to an unseasonably warm winter during the study period. This could be evidence of psychological adaptation, whereby residents accustomed to the seasonality of the UK expect cooler conditions and therefore come to prefer them. Cues here could include changes in daylight hours and perhaps wider media relating to this time of year. Furthermore, consideration of indoor temperature and comfort temperature revealed that this relationship is much stronger for residents from the UK, which indicates that their adaptation to the local conditions means that they are better able to control their environment to suit their comfort. While the limited number of surveys conducted so far mean that these findings are far from conclusive, it provides insight into thermal history and expectation in the context of a new climate.

Subsequent surveys to be conducted over the coming months will strengthen the evidence base.

Acknowledgements
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