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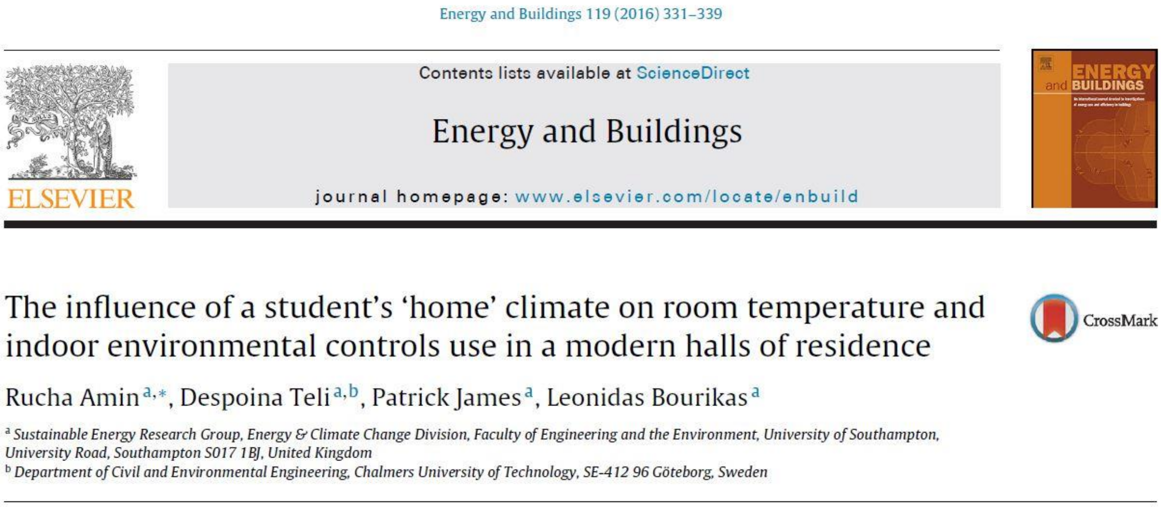

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The influence of a student's 'home' climate on room temperature and indoor environmental controls use in a modern halls of residence

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Abstract

Adaptive comfort theory states that over time people adapt to their normal environment. Therefore, people from different climates are expected to have different thermal preferences and behaviours, which could lead to ‘performance gap’ in buildings with occupants of diverse climate backgrounds. This study investigates the influence of occupants’ thermal history on use of controls and indoor temperature preference in a newly built halls of residence building complex in Southampton, UK, which provides 1104 rooms to international and UK students. A total of 223 questionnaire responses along with monitored temperature data and thermal comfort surveys from 30 rooms are used in this analysis.

The results indicate that residents’ ‘home’ climate is impacting the reported use of environmental controls in rooms with similar typological characteristics. The average indoor temperature of residents from warm climates was 2.3◦C higher than that of residents from cool climates in February 2015 (winter heating season). This difference cannot be explained by room orientation alone. Comparison of room temperatures to design values indicates that UK design standards may not account for the comfort needs of residents accustomed to warmer climates. A simple management approach to comfort optimisation is suggested, locating students on the appropriately orientated facade to reflect their ‘home’ climate.

Keywords: thermal comfort, thermal history, thermal preference, occupant behaviour, controls use, adaptive comfort, performance gap

1. Introduction

As increasing efforts are made to improve the energy efficiency and subsequent emissions of buildings, a phenomenon known as “performance gap” is being observed to a greater extent. The performance gap is best described as the difference between the actual and the expected energy consumption [1]. Broadly speaking, the performance gap can be attributed to three factors; (i) design assumptions and modelling, (ii) construction and build quality and (iii) users (including management) [1]. This paper focusses on the role of users and of design assumptions regarding indoor temperatures on the energy performance of a modern halls of residence building.

As Grandclément et al. [2] indicate, energy use in buildings is socio-technical whereby users take a more active role than merely being passive receivers of design strategies. Given this, it becomes necessary to understand how users interact with the indoor environment and furthermore to address diversity in these interactions. Numerous studies have investigated the contribution of occupant behaviour on energy use and have found it to be a significant factor, though the degree of significance varies from study to study [3,4,5,6,7]. A key driver of user behaviour in the indoor environment is achieving comfort and thermal comfort in particular is seen as the most significant contributor to overall user satisfaction [8].

1.1 Thermal comfort and adaptation

A number of standards and guides have been developed in order to help designers meet the comfort needs of occupants such as ASHRAE 55 [9], ISO 7730 [10], CEN Standard EN15251 [11] and CIBSE Guide A [12]. These standards were primarily based on the heat balance approach to thermal comfort developed by Fanger [13] which uses the Predicted Mean Vote and Percentage Predicted Dissatisfied (PMV/PPD) indices. However, Fanger’s model, developed from climate chamber studies with American and Danish students, has been criticised for not adequately reflecting the variability in comfort temperatures found in field studies around the world [14]. This has led to the development of an alternative approach to thermal comfort known as adaptive thermal comfort.

Adaptive thermal comfort theory states that people take actions to restore their thermal comfort in order to compensate for changes in their thermal environment [14]. The theory also appreciates that comfort temperatures are likely to be influenced by recently experienced climate conditions and that occupants are more likely to achieve comfort when they have control over their local environment. Additionally, thermal sensation is said to depend on outdoor climate and the expectations it creates about the indoor environment [15]. The thermal adaptive mechanisms can be distinguished into three categories [16]:

a) Behavioural—behavioural adjustments include actions that aim to improve the indoor climate or the thermal state of the body and can be personal (e.g. clothing and posture changes, activity, moving to different locations), technological (e.g. opening/closing windows or blinds, controlling fans or HVAC systems) or cultural (e.g. schedule adjustments or dress code).

b) Physiological—physiological adaptation includes all the physio- logical changes that result from the exposure to climate and that can lead to greater tolerance to the climatic conditions.

c) Psychological—psychological adaptation refers to changed perception due to past experience. Having adapted one's expectations to the indoor conditions experienced results in occupants having greater tolerance to temperature fluctuations.

de Dear and Brager [16] concluded, based on results from field studies, that the contribution of physiological adaptation or acclimatisation in explaining the difference between the comfort levels of occupants in naturally ventilated and air condition buildings was negligible. However, some studies have shown that repeated exposure to hot or cold environments can result in physiological adaptation or acclimatisation [17,18,19]. One such study, conducted by Yu et al. [19] investigated the difference in physiological responses between subjects accustomed to air conditioned and naturally ventilated indoor environments in 'heat shock' scenarios. With the small sample employed (10 in each group, air conditioned and naturally ventilated), Yu et al. [19] found that those accustomed to naturally ventilated environments did not report feeling as hot or uncomfortable as the AC group.

A further study by Yu et al. [20] investigated the long term impact of access to indoor heating on levels of physiological response by considering sub groups from Shanghai and Beijing separately. This is based on Chinese legislation which stipulates that indoor heating systems be installed only if more than 90 days in the year see a mean air temperature of 5 ◦C or less [20]; Beijing does fall under this category and thus indoor heating is common whereas Shanghai does not. This study presented 2 significant findings: (i) the skin temperature of the participants from Shanghai decreased faster than those from Beijing, which indicates a greater degree of vasoconstriction and (ii) participants from Beijing presented significantly more instances of shivering, which implies that they require more extreme homeostatic mechanisms to maintain core body temperature [20]. Since Shanghai experiences warmer winters than Beijing and therefore has no indoor heating, these findings suggest that indoor thermal history is more significant than outdoor thermal history in determining physiological acclimatisation [20].

In contrast to physiological adaption, the significance of behavioural and psychological adaption in determining comfort temperatures remains uncontested. Thermal comfort field studies have been carried out across the world for decades and it has been shown repeatedly that indoor comfort temperatures can vary in different local climate conditions [21,22,23]. This is explained by a combination of behavioural and psychological adaptive processes. Moreover, many studies in hot and humid climates have shown that occupants of naturally ventilated buildings have a wider range of comfort temperatures than those in air conditioned buildings. This provides further evidence of the importance of past experience and expectations of the indoor environment in determining thermal comfort [24,25,22,26,27].

It is evident that past experiences and exposure to a specific climate, both indoor and outdoor, can impact occupant behaviour and indoor temperature preference. Students in the UK come from various locations around the world having experienced very different climatic conditions. Their diverse thermal and cultural history could have an impact on their adaptive behaviour when they move into a UK halls of residence. This study aims to investigate the level of diversity in indoor temperatures and use of indoor environmental controls and to explore factors which may be influencing this with a focus on climate history. This has been done using a case study building; Southampton University's newly built Mayflower Halls of Residence complex, which was completed in the summer of 2014 and first occupied in September of the same year. Southampton is a major port city with a population of 250,000 located 120 km south west of London.

1.1 Mayflower Halls of Residence case study

The Mayflower Halls of Residence complex is comprised of 3 separate buildings providing a total of 1104 rooms; Fig. 1 shows a general plan of the three buildings and their orientation. The majority of rooms are single occupancy, ensuite rooms, arranged in cluster flats with shared kitchen/living room area where the number of rooms per flat varies; a small number of accommodation rooms are studio flats. The buildings are naturally ventilated with individual heating controls in each room (0–5 dial on radiator) and top opening tilt windows. It should be noted that all utility bills are included with the price of the rent so there is no financial incentive for the residents to be energy conscious with respect to heating. As part of the planning conditions for the development, this building was required to undertake a Post Occupancy Evaluation (POE) within one year of occupation; some of the results from the POE are used in this study. Fig. 2 shows a thermal image of the south east facade, as indicated in Fig. 1, taken in March 2015. The image was taken before sunrise to eliminate the influence of solar radiation on the results. The ambient temperature at the time the image was taken was 5 ◦C. As can be seen in the figure, there is significant heat loss from the open windows with rooms displaying varying degrees of window opening; some closed, some fully open and some partially open. This shows a variable use of indoor environmental controls, in this case window use pattern, which as various authors have indicated [28,4] can have implications for buildings energy performance. This paper further investigates the variability in window opening and heater use behaviour of students through questionnaires and indoor environmental measurements.

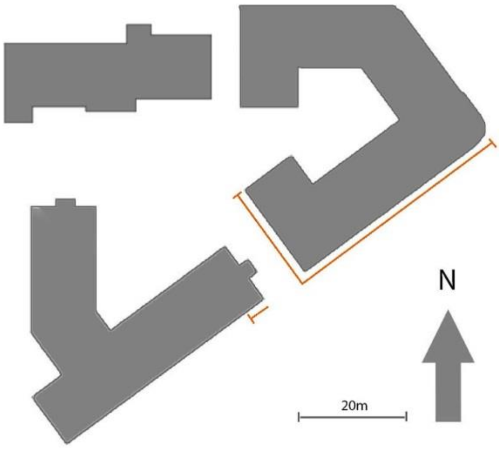

Fig. 1. Schematic diagram of the layout of Mayflower halls of residence complex located in Southampton, UK. The orange lines highlight the south east facade shown in Fig. 2

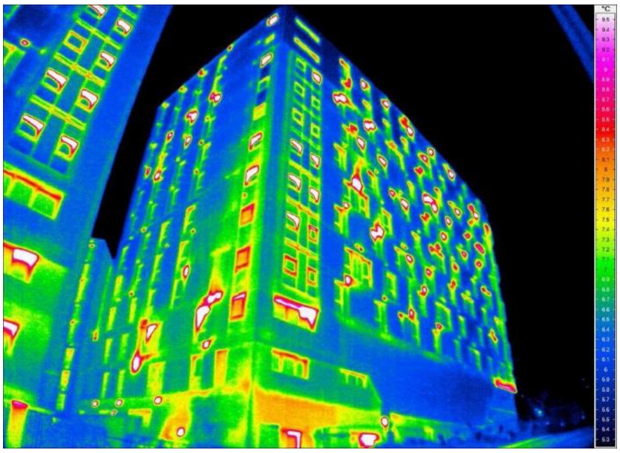

Fig. 2. Thermal image of south east facade of Mayflower halls of residence taken before sunrise on 19/03/2015 as highlighted in Fig. 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The following two sections of this paper (Sections 2 and 3) are divided into two sections. 'Part 1–Online Survey' uses the results from an online POE questionnaire to understand diversity in use of indoor environmental controls. 'Part 2–Environmental Monitoring and Thermal Comfort Surveys' considers monitoring of temperature and humidity in conjunction with the same questionnaire to investigate in more detail and with a smaller sample, indoor air temperature and factors which may influence this. Thermal comfort surveys are also included in this section.

2. Methodology

2.1 Part 1–Online Survey

An online post occupancy evaluation questionnaire was sent by email to 955 (out of a total 1029) residents of Mayflower Halls of Residence in March 2015 using the University of Southampton's iSurvey software. The online survey, approved by the University ethics review committee, consisted of questions relating to the occupants level of satisfaction with the building in general, their opinion on the indoor environmental conditions in their bedroom, use of indoor environmental controls such as heating, window opening, curtains and artificial lighting and some details about them. This resulted in 223 questionnaires returned representing a response rate of 22%.

Participants were asked which city they had mostly been living in for the two years prior to moving into the case study building. These responses were then broadly grouped into “cool/cold” (Category A) or “warm/hot” (Category B) climates based on the Köppen-Geiger climate classification system [29]. Category A climates were taken to be any warm temperate, snow or polar climates with corresponding cool, cold or polar temperature classification based on winter temperatures. All others were considered to be Category B climates. In all cases, the category was decided based primarily on the average winter temperatures. The aim of this system of classification is to group participants into those who have regularly experienced winter as cold as or colder than the average UK winter and those who have not. Fig. 3 shows the previous location of residence (‘home’ climate) for the 220 respondents who provided an answer to this question. The blue dots represent those from Category A climates (174 respondents) and the orange dots represent those from Category B climates (46 respondents).

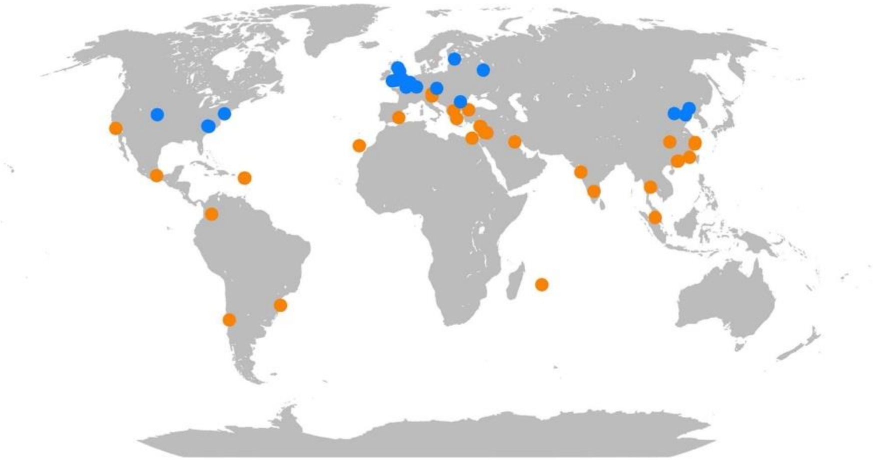

Fig. 3. World map showing previous residence of online POE survey respondents for the two years prior to living in the case study building where the blue dots represent Category A(cool/cold climates) and the orange dots represent Category B (warm/hot climates). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2 Part 2–Environmental Monitoring and Thermal Comfort Surveys

Temperature and relative humidity data loggers (MadgeTech RHTemp101A) were placed in 78 rooms in Mayflower Halls in November 2014; these 78 participants were specifically excluded from participating in the online POE survey outlined in Section 2.1. Rooms were selected based on position in the building complex so as to provide a representative sample taking account of floor level and orientation in all 3 buildings. The data loggers recorded single reading measurements of temperature and relative humidity every 5 min and were placed in one of two positions in each room depending on layout of the room and ease of access. The locations were chosen such that they remained out of direct solar radiation and to cause as little disruption to the occupants as possible.

These 78 participants were then contacted in May 2015 in order to carry out the POE questionnaire, conduct a thermal comfort survey and arrange collection of the data loggers. The questionnaire was largely identical to the online POE survey outlined in the previous section (Section 2.1) with an additional section addressing thermal comfort at the time of the survey. For the assessment of thermal sensation, the 7-point ASHRAE scale was used [9] with a 5-point thermal preference scale. The questionnaire survey was conducted in conjunction with indoor environmental measurements of air temperature, relative humidity, globe temperature and air velocity using the portable DeltaOhm HD32.3 instrument. Comfort temperatures, T_{com}, were calculated using the Griffiths method which uses the globe (operative) temperature, T_{op}, measured during the face-to-face questionnaire along with the thermal sensation vote. The Griffiths constant is taken to be 0.5 [30]:

$$T_{com} = T_{op} + TSV/0.5 \qquad (1)$$

where T_{op} is the operative temperature at the time of the survey and TSV the thermal sensation vote. A total of 30 residents took part in the interview questionnaire resulting in 30 complete questionnaires (including thermal comfort responses) with corresponding temperature and humidity data for the 5 previous months. Fig. 4 shows the location of residence of these 30 participants for the two years prior to moving into the case study buildings, grouped into Category A (cold/cool) and Category B (warm/hot) climates and represented by the blue and orange dots respectively.

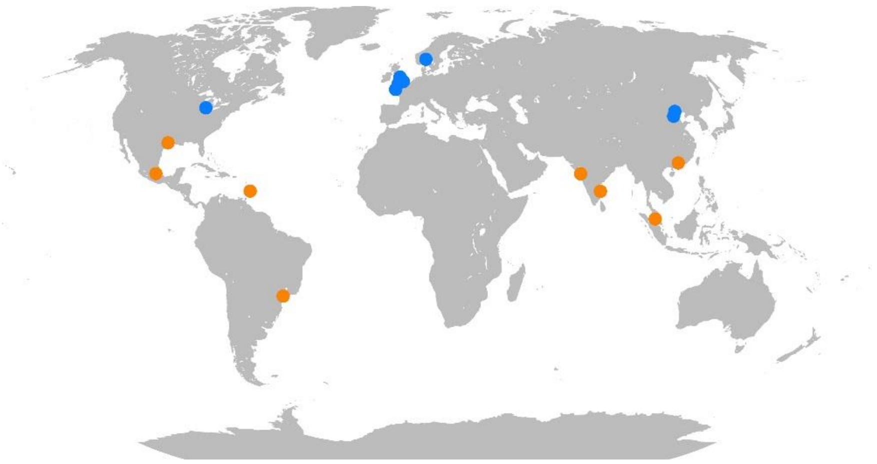

Fig. 4. World map showing previous residence of 30 environmental monitoring participants for the two years prior to living in the case study building where the blue dots represent Category A(cool/cold climates) and the orange dots represent Category B (warm/hot climates). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results & Discussion

3.1 Part 1–Online Survey

Of the 223 respondents to the online survey, 123 (55%) were female, 96 (43%) were male and 4 (2%) did not state. The age of respondents ranged from 18 to 52 with 139 (62%) being 18–19, 61 (27%) being 20–24 and 21 (9%) being 25 or over; 2 respondents' (1%) ages are not stated. The number of hours reportedly spent in the bedroom (i.e. their private space) including sleeping time on a typical weekday and typical weekend day are shown in Fig. 5. This indicates a highly irregular occupancy profile distribution in comparison to office buildings or households with some respondents reporting spending less than 5h in their bedroom and others reporting 23h; this represents a standard deviation (σ) of 3.1. It is possible that some of the responses that indicated a very low number of occupancy hours were due to a misunderstanding of the question on the part of the participants such that sleeping time was not included in their response despite the question stating that it should be. Greater variation in number of hours spent in the bedroom is evident on a typical weekend day with responses varying from 0 to 24 and a standard deviation (u) of 4.6. Observing such variation in number of reported occupancy hours indicates clearly how challenging this type of building is to predictively model. It would be unrealistic to hold it to any of the existing occupancy profiles for residential buildings where occupancy hours are taken to be in the region of 13h for a working couple or 20h for a retired couple [31] as shown in Fig. 5. This in part may be due to the mixed use of such buildings where bedrooms serve also as study and social spaces and where students' lecture schedules vary greatly especially between degree programs.

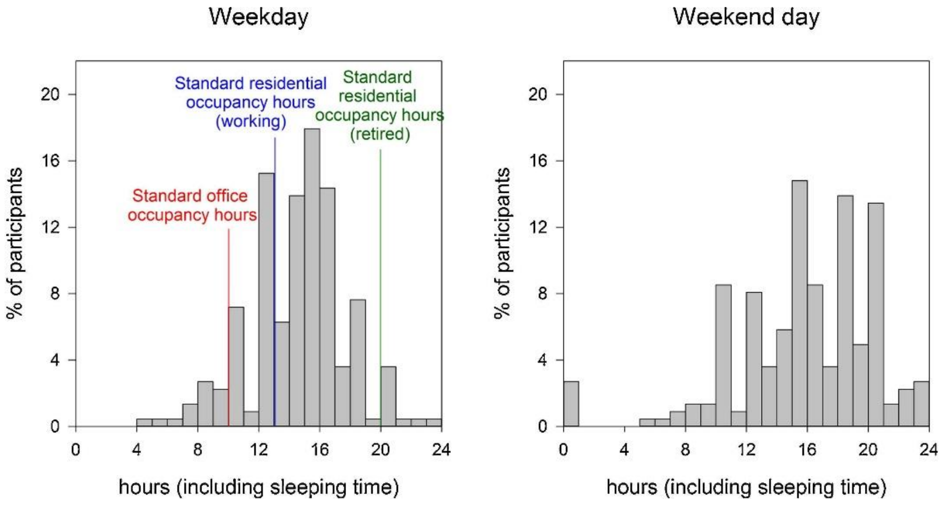

Fig. 5. Histogram showing reported number of hours spent in the bedroom (including sleeping time) by residents of Mayflower halls of residence complex during a typical weekday (left) and weekend (right) day. Also shown are some benchmark values for number of occupancy hours [37] for office buildings (red) and for two typical residential scenarios, working (blue) and retired occupants (green) [32]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Responses to questions on the frequency of use of indoor environmental controls, specifically use of heater, window opening and use of curtains show diversity in the reported behaviour of occupants (Fig. 6). Use of the heater shows a relatively even spread across the categories with a majority reporting using the heating controls less than once per month ("never"); this does not, however, specify the setting the heater is left at for most of the time. Respondents demonstrated a high rate of window opening and curtain use with 76% and 77% respectively reporting using these controls either daily ("often") or more than once a day ("frequently"). As with use of heating controls, it is not specified whether those reporting opening windows or curtains less than once per month have these controls open or closed for the majority of the time. However, infra-red imaging indicates that a significant percentage of windows are in the open state during the heating season as shown in Fig. 2.

When the use of controls are considered by gender, male participants reported using both windows and curtains more than once a day ("frequently") significantly more than female respondents. In the case of curtain use, this was 47% for males and 33% for females and for windows, 50% for males and 37% for females. In both cases, females have a higher representation for the next category representing use of these control daily ("often"). By contrast, male respondents report using their heating controls less than once per month ("never") more than female respondents (40% and 25% respectively) with female respondents carrying a higher percentage in categories representing more frequent use of heating controls. However, these differences, shown in Fig. 6, are small and could imply that factors other than gender play a more significant role in determining behaviour with respect to indoor environmental controls e.g. familiarity with type of heating system or control regime in previous residence.

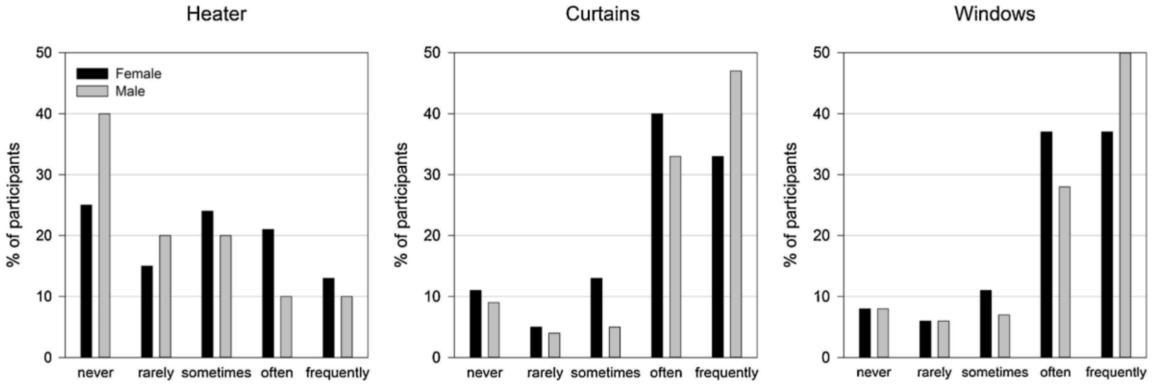

Fig. 6. Occupants' reported use of indoor environmental controls for heating, curtains and window opening classified by gender where "never" is less than once per month, "rarely" is once per week, "sometimes" is 1–2 times per week, "often" is daily and "frequently" is more than once per day.

Finally, the use of controls were examined with respect to previously experienced climate; a description of how the participants were grouped into Category A (cold/cool) and Category B (warm/hot climates) is given in Section 2.1. Since there were significantly more responses from

Category A climates (174) than Category B climates (46), the use of indoor environmental controls are considered by percentage rather than absolute number (Fig. 7); 3 participants did not state the location of their previous residence. It is observed that those from Category A climates report higher use of curtains and windows with higher percentages reporting ‘frequently’ and lower use of heating controls (‘rarely’ and ‘never’).

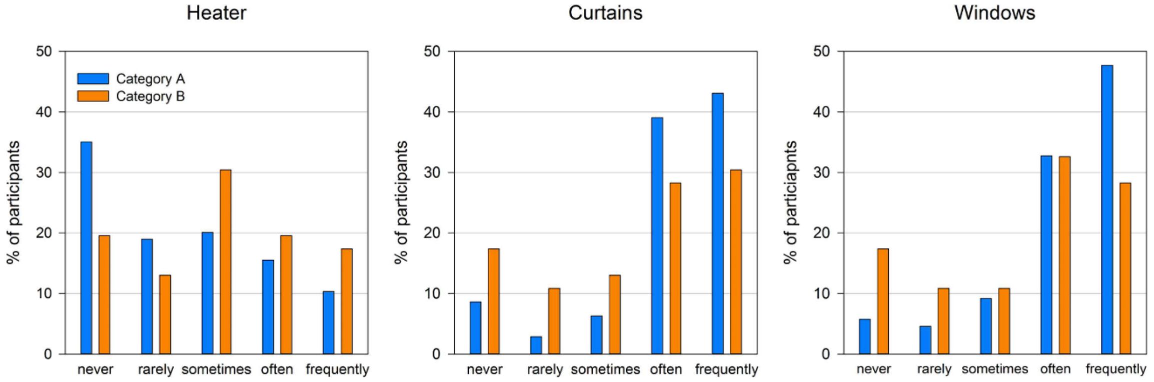

Fig. 7. Occupants’ reported use of indoor environmental controls for heating, curtains and window opening classified by climate prior to moving to the case study building where “never” is less than once per month, “rarely” is once per week, “sometimes” is 1–2 times per week, “often” is daily and “frequently” is more than once per day. Category A refers to “cool/cold” climates and Category B to “warm/hot” climates.

To understand how use of indoor environmental controls affects overall satisfaction with the indoor environment, the use of controls is shown along with responses regarding how occupants describe the temperature in their rooms during the winter. The majority (56%) of the residents feel that the temperature is satisfactory or ‘ok’ and there are more residents reported being ‘too warm’ (8%) than ‘too cold’ (2%). Responses indicating slightly ‘too warm’ or ‘too cold’ are similar in number at 18% and 15% respectively. Considering heater use, it is interesting to note that those who report being satisfied with the indoor temperature in their bedroom are the dominant group across all categories of heater use. This implies the importance of end user control of the indoor environment to achieve satisfaction and comfort. Furthermore, those that report feeling ‘too warm’ or ‘a bit too warm’ are strongly represented in the category of ‘never’ using the heater and ‘frequently’ using the windows. This implies adaptive comfort behaviours, despite residents not being entirely satisfied with the resulting temperature conditions. However it is unclear at this stage whether or not these adaptations can be said to be effective since the circumstances under which each type of action is taken is not stated.

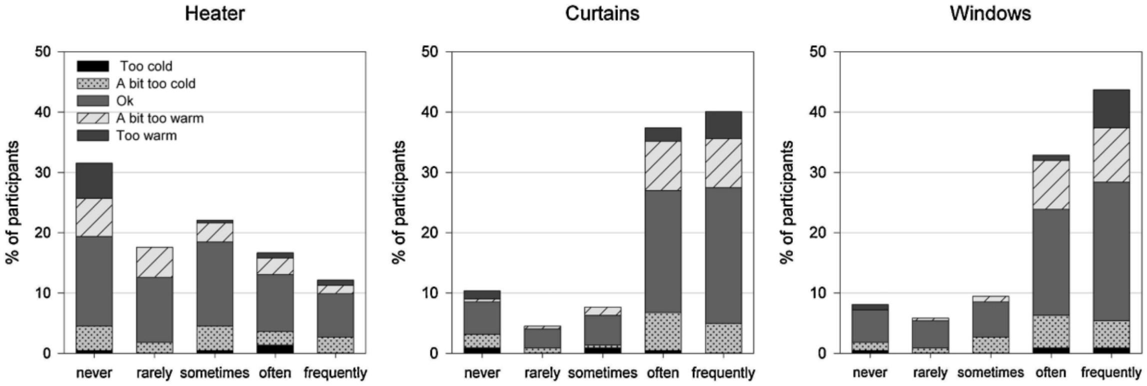

Fig. 8. Stacked bar chart showing occupant's reported use of indoor environmental controls categorised by occupants' general description of indoor temperature during the winter (223 respondents). "Never" is less than once per month, "rarely" is once per week, "sometimes" is 1–2 times per week, "often" is daily and "frequently" is more than once per day.

Part 2–Environmental Monitoring and Thermal Comfort Surveys

Monitored data of temperature and relative humidity at 5 min intervals was collected from December 2014 to May 2015 in 30 rooms of Mayflower Halls alongside the same questionnaire used in Section 3.1 relating to use of indoor environmental controls. The results showed average indoor temperatures varying from 19 ◦C to 29 ◦C, with minimum and maximum temperatures reaching 12.4 ◦C and 32.9 ◦C respectively. Since a certain degree of variation is expected over the year due to seasonal weather changes, a shorter period of time, the month of February 2015, was considered. This month was selected as it is during the heating season and academic term time so the student residents would be occupying the buildings. The mean outdoor temperature for this period was 4.1 ◦C in the South of England, which is 0.4 ◦C lower than the long term (1981–2010) average for this month [32]. It was observed that mean indoor temperature ranged from 19 ◦C to 32 ◦C, where the standard deviation (u) of these means is 2.4. Fig. 9 shows the air temperature distribution of these 30 rooms for February 2015, where the box plots represent the 10th, 25th, 75th, 90th percentiles and median, the red line represents the mean and the outliers are shown by the grey circles. Since occupancy was not monitored in this instance, the data presented in Fig. 9 is of all recorded temperatures for the month of February. It can be seen that while the majority of the samples presented here have mean values that lie within the recommended indoor temperature range for heating, taken from EN 15251 [11], they all have values outside this range as depicted by the grey circles. This has implications for the design process since it is likely that mean values of indoor temperature are used in energy models and it is evident that these may not lead to acceptable indoor temperatures at all times, which could lead to negative feedback at the POE stage, depending on frequency of occurrence. Interestingly, as seen in Fig. 8, students' general feedback on their room's temperature is positive, which means that the range of room temperatures for this diverse population is acceptable overall. This is perhaps a reflection of the 'bundled' charging mechanism for rent and heating resulting in residents being able to use windows or heating controls without financial penalty.

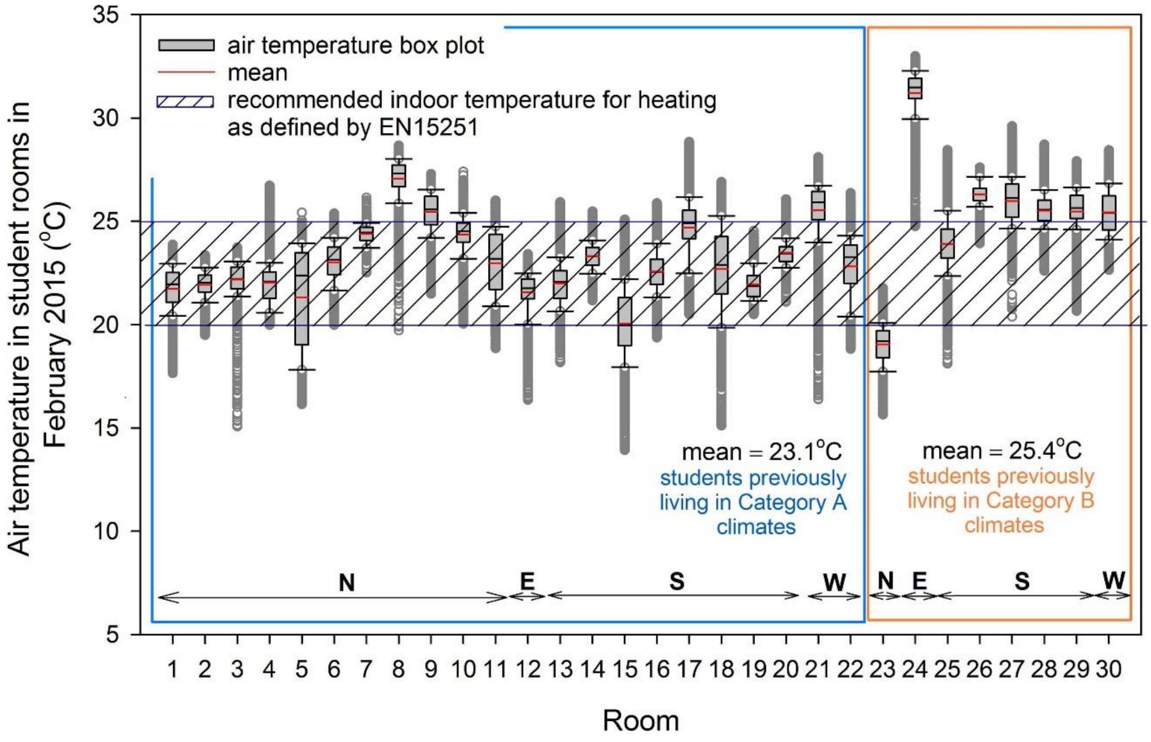

Fig. 9. Boxplot of air temperature in 30 monitored rooms of Mayflower Halls of residence for February 2015 where the 10th, 25th, 75th, 90th percentiles and median are shown in the boxplot. The red line represents the mean and outliers (below 10th or above 90th percentile) are shown as the grey circles; students previously living in Category A (cool/cold) climates are shown in the blue box and Category B (warm/hot) climates are shown in the orange box. The rooms are grouped by facade orientation: North (N), South (S), East (E) and West (W) shown by the arrows. The shaded area represents the recommended indoor temperature for energy calculations taken from EN 15251:2007 [11]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Considering the orientations of the rooms, which could influence the indoor air temperature, it was found that in the Category A group, the average temperature for February 2015 for north facing rooms was 23.3 ◦C compared to 22.6 ◦C in South facing rooms. For the purpose of this study, north facing rooms include north-west and north-east and south facing rooms include south- west and south-east as north-south orientation will have the most significance during the winter. If room orientation was strongly influencing indoor room temperature we would expect that the south facing rooms would have a significantly higher temperature, than the north facing. Instead, we see the north facing rooms displaying higher temperature though the difference cannot be said to be significant. This implies that room orientation may not be the most influential factor in determining room temperature during the heating season where it is likely that all rooms will require additional heating to maintain a comfortable temperature. However, further research is needed to confirm this as the room sample size employed here is small.

The participants were also asked to rank their overall perception of the temperature conditions in their bedroom during the winter where the response options were: Too cold (−2), A bit too cold (−1), Ok (0), A bit too warm (1) or Too warm (2). It is interesting to note that the average for the participants from Category A climates was 0.2, indicating that on average, these residents feel slightly warm and for the Category B participants, the average was −0.4 which implies that despite having a higher average indoor temperature, residents from warmer climates still report feeling slightly cool in the building. These responses are plotted against the rooms' mean indoor temperature in Fig. 10.

Considering then the cases where the mean indoor temperature value lies above the recommended range (20–25 ◦C), it is interesting that only one participant (Room 27) answered "Too hot" when asked to describe the indoor temperature during the winter. Perhaps more notable however, is that 3 of the 6 Category B participants (Rooms 24, 28 and 29) whose mean temperature is above the recommended range all reported being either too cold or a bit too cold despite having average temperatures over 25 ◦C, with one (Room 24) having an extremely high average of 31 ◦C. By contrast, the three participants from Category A climates whose mean values were above the recommended range all responded 'Ok' when asked about the temperature conditions in their rooms. This implies that while on paper, these indoor temperature would be considered unacceptably high, in this instance, they are satisfactory for the occupant. In Fig. 10, an additional category has been added to the data set which highlights the occupants from cool, non-UK climates; these are represented by the blue squares. It can be seen that there is only one resident from the UK whose living space is on average outside the EN 15251 recommended indoor temperature range for heating (20–25 ◦C) [11].

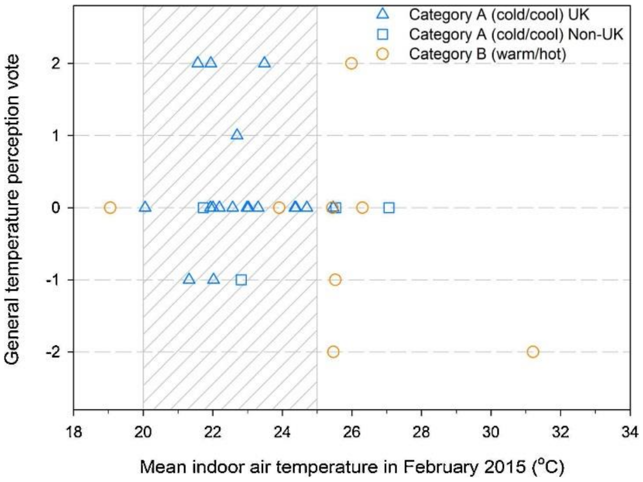

Fig. 10. Plot of overall temperature perception vote for the winter against mean indoor temperature for February 2015 where −2 is "too cold", -1 is "a bit too cold", 0 is "ok", 1 is "abit too warm" and 2 is "too warm" on the y axis.

As highlighted earlier, the monitoring data presented here includes all recorded values for the month of February 2015, not specifically occupied times. It is therefore possible that these monitored temperatures do not necessarily reflect participants' preferred temperatures. For example, radiators left on or windows left open while residents are not occupying their room could result in temperatures being higher or lower than preferred temperatures. Fig. 11 shows the comfort temperature calculated using the Griffiths method against the mean monitored temperature for February 2015 of the 30 accommodation rooms coloured by climate of previous residence. The regression line of all data points shows that the comfort temperature is correlated to the mean monitored temperature in February (r = 0.65, p = 0.0001) with $T_{com} = aT_{mon} + b$. Therefore, the mean monitored temperature can be taken to closely represent overall thermal preference.

As can be seen in Fig. 11, respondents' comfort temperatures ranged between 19 ◦C and 28 ◦C, in close agreement with the range in mean monitored room temperatures in February (19–31 ◦C). Thus, it seems that the diversity in temperature preference may not be sufficiently well catered for in the case study building given that many residents have expectations and adaptations that are significantly different than those accounted for in the relevant building standards. This will affect the buildings energy performance thereby highlighting user driven performance gap in a halls of residence context.

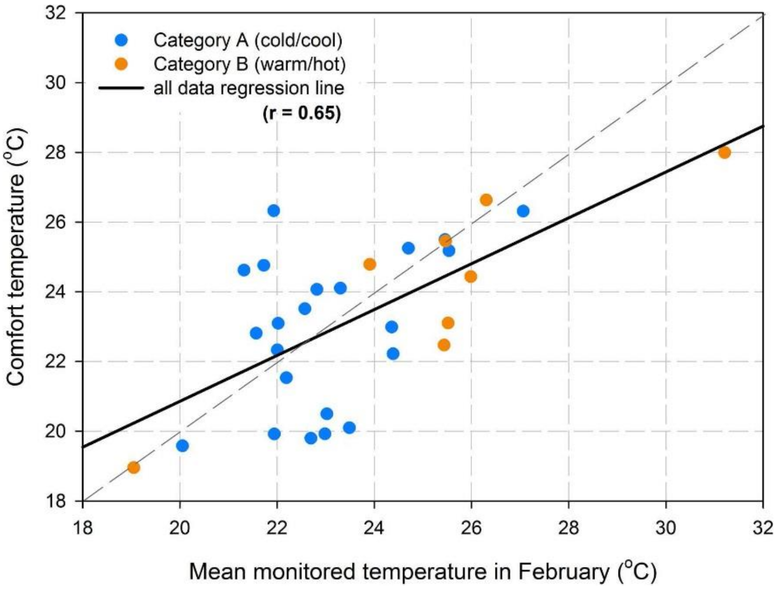

Fig. 11. Comfort temperature calculated using the Griffiths method plotted against mean monitored indoor air temperature in February 2015 of 30 accommodation rooms of Mayflower halls. The solid black line shows the regression line using all data points.

4. Conclusion

In this paper, results from on an online POE study of a newly built halls of residence complex were used to examine the level of diversity in how occupants use the indoor environmental controls available to them. Whilst it is likely that some of this variation is due to differences in the conditions in the rooms due to orientation and floor level, it is inferred from this study that there are other influencing factors at play. Some of these, such as level of proactivity in addressing thermal discomfort which is largely a personality trait, are hard to address and impossible to predict. However, differences observed in use of controls by occupants from Category B (warm) climates indicate that there are factors relating to long term thermal history, previous experience of indoor environments and perhaps cultural practices that are driving behaviour. While this initial study does not draw any generalisations, should it be more fully understood, this type of parameter has the potential to be included in the design process either as an input at the design stage or as part of a post occupancy, 'Soft Landings' approach [33].

The second part of this study used monitored air temperature measurements for February 2015 along with questionnaire results and thermal comfort surveys to investigate variation in indoor temperatures in 30 rooms of the case study building complex. The average monitored air temperatures in the rooms were found to be correlated with comfort temperature which implies that they can be taken to be a reasonable indicator of overall preferred temperature. Mean air temperatures ranged from 19 ◦C to 31 ◦C with a standard deviation (u) of 2.4. Whilst indoor temperatures cannot be expected to be uniform throughout a building like this, where there are many influencing factors both in building design and occupant preferences, this large range is striking. The mean values of temperature are also noteworthy when considered with respect to the recommended indoor temperature range for heating (20–25 ◦C). It was found that almost all the mean values that lay above this range were of rooms where the occupant had, for the two years prior to living in the case study building, been living in a warm or hot climate. Furthermore, some of these occupants reported finding the temperature in their room was generally too cold (or a bit too cold). This difference in indoor temperature preference is even more evident when considering residents from cool non-UK climates. It is shown that all but one of the rooms that had a mean temperature outside the 20–25 ◦C range belonged to residents who have previously not been living in the UK. Furthermore, in this study, room orientation did not appear to be a factor in determining winter season indoor room temperature.

While the sample sizes presented here are too small to form generalisations they are comparable to other comfort studies conducted in similar residential contexts [34,35,36]. The findings present an interesting question of whether or not buildings designed for UK standards are able to meet the comfort needs of international residents and moreover how this can be addressed in the future. It is also expected that over time, residents from differing climates are likely to adapt to the thermal conditions in their new environment. However, since this study has only considered one month in the year (February 2015) and the residents would all have moved in four months prior (October 2014), it is not possible to say how much (if at all) of this adaptation has taken place. Further work will need to be carried out in the earlier months of residents' occupancy in order to investigate this lag in adaptation time. This is of particular interest in this case due to the unique nature of the building where, for the most part, there is a new set of occupants each year. This adaptation time lag could have significant implications for overall energy performance.

Further research is necessary to understand how best to address the issues of varying preferences and behaviour based on climate history. This work raises some interesting questions on how best to develop inclusive management and design strategies to account for significantly different indoor temperature preferences. For example, in situations where it is expected that there will be residents with diverse climate histories (as in the case study used in this paper) it is possible to design specifically for multiple indoor climates. This would create a zoned system where different areas could provide comfortable living conditions for residents with varying thermal preferences. Alternatively, in cases of existing buildings, a management strategy could be developed to profile residents based on climate history before arrival and locate them in rooms that are likely to match their existing preferences. This could include, for example, placing a resident who is expected to have a preference for higher temperatures in a sheltered high floor level south facing room to optimise both solar gain and stratification effects. This would also allow rooms that are likely to be cooler to be occupied by residents who have a preference for lower indoor temperatures. This strategy would also reduce summer overheating risk as occupants with higher winter temperature preference are likely to tolerate higher summer temperatures. This could present a simple solution to improving comfort by optimising the characteristics of the building to suit the specific needs of the occupants.

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