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TECHNICAL ARTICLE

Exploring the Link between Thermal Experience and Adaptation to a New Climate

Rucha Amin*, Despoina Teli*,† and Patrick James*

Numerous field studies conducted in different locations have found that peoples' thermal comfort varies with local climate. However, little is understood about the effect of moving from one climate to another. Literature suggests that people would be able to adapt to the typical indoor climate in a new location, though estimated timescales for this process differ. This paper uses data from a 6-month field study to investigate the process of thermal adaptation to a new climate. The field study consisted of a series of four thermal comfort surveys conducted with 48 occupants of single occupancy residential accommodation units, which helped to estimate their preferred temperatures. The surveys were carried out between October 2015 and April 2016 in Southampton, UK, with high resolution indoor air temperature data collected for the periods between the surveys.

Study participants were grouped into three categories: long term residents of the UK (Category A), recently moved to the UK from cold climates (Category An) and recently moved to the UK from warm climates (Category B). The higher indoor temperatures of participants from cool climates (Category An) indicates the influence of indoor thermal history in determining thermal comfort conditions in a new location. This is highlighted by the fact that 94% of Category An participants reported having heating in their previous residence compared to 17% of Category B participants. Analysis of comfort temperatures over the first 6 months of occupancy shows no indication that occupants from Category An or B are adapting their indoor preferences to match that of long term UK residents, given the choice to create their preferred environment. Finally, comparison of indoor air temperature and comfort temperature found a higher correlation in Category A participants which supports the key principles of adaptive comfort theory. Category An demonstrated fairly close correlation though air temperatures were higher than comfort temperatures which may be due to embedded heater use behaviour patterns. Category B demonstrated no correlation between comfort temperature and air temperature which may be due to unfamiliarity to indoor heating systems.

Keywords: adaptive thermal comfort; indoor temperature; occupant behaviour; thermal history; comfort temperature; heating

1. Introduction

Many field studies have been conducted in various climates across the world which demonstrate that comfort temperature is closely linked to local climate (Brager & de Dear 1998; McCartney & Nicol 2002; Nicol 2017; Taleghani et al. 2013; Zhang et al. 2017). Adaptive thermal comfort theory explains this phenomenon with respect to occupants' active engagement with their indoor environment (de Dear & Brager 1998; Nicol et al. 2012). This is to say that if an environment causes an occupant discomfort, they are likely to take responsive actions to restore comfort (Nicol & Humphreys 2002). These responsive actions are said to be rooted in one of three types of adaptation: behavioural, physiological or psychological (Brager & de Dear 1998). Conceptually, all three can be linked to local climate in some way however these relationships have not been studied rigorously (Schweiker et al. 2012).

Despite the fact that adaptation is a fundamental aspect of adaptive thermal comfort theory, little research has addressed the nature of adaptation or the influence of thermal history on current preferences. The majority of the studies addressing thermal history have been conducted by Luo et al. in China and employ groups of participants moving between Northern and Southern China (Luo, Ji, et al. 2016; Luo, Zhou, et al. 2016; Luo, de Dear, et al. 2016). A key factor in these studies is the availability of district heating in northern regions where the climate is described as 'severe cold' (Luo, de Dear, et al. 2016). In contrast, southern

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regions are not provided with district heating despite cold winter temperatures. The key findings from this group of chamber and field studies are firstly that occupants adapt more easily to neutral conditions than more severe conditions (Luo, de Dear, et al. 2016). Secondly, these studies find that in addition to local climate, indoor thermal history influences thermal adaptation (Luo, Ji, et al. 2016; Luo, de Dear, et al. 2016). This is also supported by findings from a climate chamber study which investigated differences in thermal preferences between participants from Nigeria, Turkey and Hungary (Kalmár 2016).

This study aims to compare the thermal preferences and adaptation of occupants from different climate zones after they moved to a new location. Further to this, presented here is an investigation into the relationship between thermal experience and change of thermal preferences in a modern residential building taking into account seasonal variation in local weather conditions.

2. Study Design

Field studies of thermal comfort typically involve structured subjective responses to indoor conditions (ISO 2005; ASHRAE 2013) alongside measurements of the environment using a sensing station (ISO 2001). Increasingly, studies are also employing air temperature and humidity monitoring devices for longer term assessment of the indoor environment. The Griffith's method is a commonly used method for determining the comfort temperature of participants in studies with relatively small sample sizes (Griffiths 1990; Nicol et al. 2012). This simple method linearly adjusts the operative temperature (T_{op}) based on participants vote (TSV) on the seven point ASHRAE thermal sensation scale (ASHRAE 2013) to give a comfort temperature (T_{com}) (Griffiths 1990; Nicol et al. 2012):

$$T_{com} = T_{op} - TSV/0.5$$

In order to investigate the link between thermal experience and adaptation to a new climate, a mixed methods field study was developed. The field study was conducted in the University of Southampton's Mayflower halls of residence complex (Section 2.1). Convenience sampling was used which resulted in a total of 47 participants. The study includes an in-depth participant questionnaire, a series of four thermal comfort surveys and long term, high resolution indoor temperature monitoring conducted during the academic year commencing in 2015. A timeline for the surveys is shown in **Table 1**. The first questionnaire, conducted within a month of the start of the occupancy period, included details of participants' background such as location (city and country) of previous residence and availability of heating and cooling in previous residence. The thermal comfort survey, conducted with the initial survey and a subsequent 3 times, was based on the questionnaire used in the SCATs database (McCartney & Nicol 2002). Notably, this included thermal sensation on a 7 point ASHRAE scale (ASHRAE 2013): cold, cool, slightly cool, neutral, slightly warm, warm, hot.

All face to face surveys were conducted in participants' accommodation rooms and were accompanied by measurements of the indoor environment (air temperature, radiant temperature, air velocity and relative humidity). These were taken using the ISO 7726 (2001) compliant DeltaOhm HD32.3 portable sensing station. These measurements, along with the subjective thermal sensation responses allowed for the calculation of comfort temperature using the Griffiths method as described above. During the first survey visit, an air temperature and humidity data logger (MadgeTech RH101A) was installed in each participant's room. The logger was placed in one of two locations chosen to ensure no direct solar radiation or heat source and was set to record single measurements of the air temperature at 5 minute intervals. For the purpose of this investigation, three 1 week monitoring periods between surveys were selected (**Table 1**). Selection of the time period was based on equidistance from surveys either side while also avoiding university holiday periods where occupants were likely to be away. **Figure 1** provides a timeline showing the month of the comfort surveys and the selected monitoring periods.

Participants were grouped into three categories based on average winter temperatures in the location of residence prior to occupancy in Mayflower. The categories are as follows:

Category	Description
A	Mostly living in the south of the UK for the two years prior to moving to Mayflower
An	Mostly living in a climate with winters as cold as or colder than Southampton for the two years prior to moving to Mayflower
B	Mostly living in a climate with winters warmer than Southampton for the two years prior to moving to Mayflower

Table 1: Study details and timeline with mean ambient outdoor temperature (weatherunderground 2016).

Month	Type	Start date	End date	Average monthly ambient temperature (°C)
October	Comfort survey + background	19/10/15	03/12/15	11.2
November	Monitoring	16/11/15	22/11/15	10.3
December	Comfort survey	30/11/15	14/12/15	10.6
January	Monitoring	11/01/16	17/01/16	5.8
February	Comfort survey	02/02/16	11/02/16	5.4
March	Monitoring	07/03/16	13/03/16	6.3
April	Comfort survey	18/04/16	27/04/16	8.5

2.1. Case Study: Mayflower halls of residence

The case study site is the University of Southampton's Mayflower halls of residence which is located in Southampton city centre. Southampton is a port city on the south coast of England, 75 km south-west of London, with a Köppen-Geiger classification of Cfb (warm temperate, fully humid, warm summer). The complex, comprised of three buildings, provides over 1000 accommodations rooms. These are mostly arranged in cluster flats with shared kitchen/living spaces though some studio and one-bedroom flats are also available. The location and layout of the complex is shown in **Figure 2**. Each room has top opening tilt windows (with trickle vent) and radiator with thermostatic radiator valve to facilitate personal control of the indoor environment. This was selected as suitable case study as the similarity in design of the accommodation units make comparison between occupants straightforward by eliminating variation in building construction factors which are key determinants of indoor environment. Furthermore, the high number of international students studying at the University of Southampton ensured a sampling frame with diverse thermal histories.

3. Results and Discussion

The study resulted in 47 complete data sets (N = 47) with Category A, An and B comprised of 17, 18 and 12 participants, respectively. Presented in this section are summary results of the indoor air temperatures and comfort temperatures. Also discussed here is a comparison of these two indicators of thermal preference.

3.1. Indoor temperature monitoring

Figure 3 presents box plots of monitored indoor air temperature for each of the three selected periods grouped by climate of previous residence. Also shown is the design indoor temperature range as given by the EN 15251 standard (CEN 2007). Both Categories A and B have group mean air temperatures within the recommended range whereas the Category An group means lie above this range. Category An was found to be significantly higher than Category A in November by 2.1°C and higher than Categories A and B in January, as shown in **Table 2**. The roman numerals represent statistically significant differences in comfort temperature determined by one way ANOVA (with Tukey's HSD post-hoc test). Due to non-normality of the data, as determined by Shapiro-Wilk test, ANOVA analysis could not be performed for the March data. The fact that Category An group means are above the design indoor temperature range provides further indication that European standards may not reflect the preferred conditions of some residents, leading to unexpected comfort-related performance gaps (Amin et al. 2016).

The background survey revealed that 94% of Category An residents had indoor space heating in their previous residence, compared to 17% of Category B residents. Furthermore, 76% of those Category An are from China

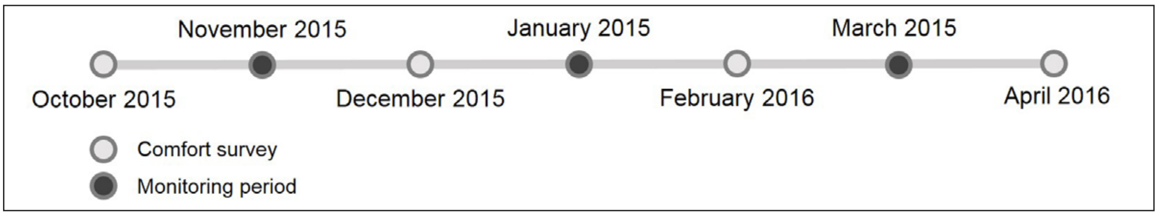

Figure 1: Study timeline showing comfort surveys and monitoring periods.

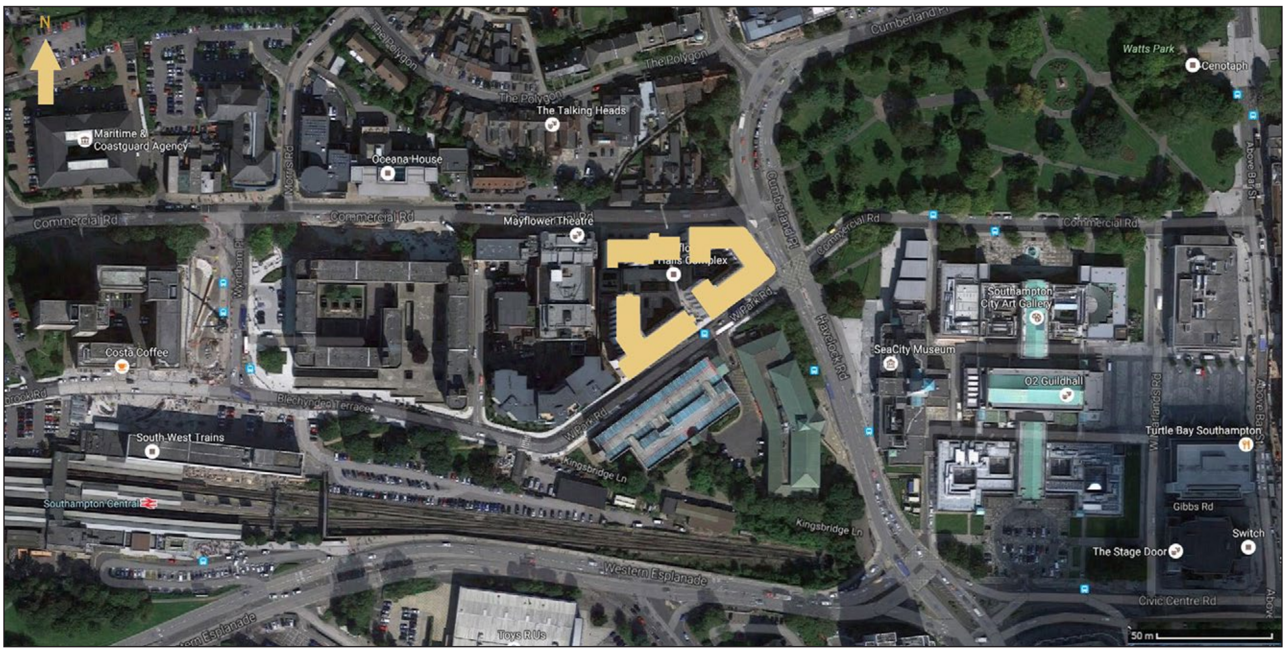

Figure 2: Map showing location and schematic outline of Mayflower halls of residence complex.

where regulation stipulates that areas in the Northern region where severe winters are typical must have government controlled district heating. It is common in these regions for homes to have no heating controls and high indoor temperatures (Cao et al. 2014; Wang et al. 2017). Therefore it is possible that many Category An residents are using their heating controls in this manner, resulting in high, but perhaps comfortable, temperature conditions. This points to the importance of behavioural and psychological adaptation in a new climate context.

Figure 3 also demonstrates that there is little change in indoor temperature in the rooms from one period to the next. This is also highlighted in **Figure 4**, which shows the hourly averaged indoor air temperature for each room for the three selected periods. Again, this is grouped by climate of previous residence (shown in colour) with the daily mean outdoor temperature included for reference (SOTONMET 2017). For all categories this is notable since it provides no indication of seasonal variability. The stable and high temperatures from November to March indicate that as a group the residents who are new to the UK, Categories An and B, are continuing to maintain their higher preferred temperatures rather than adapting to match the preferences of the long term residents. This calls into question the utility of passive climate chamber studies investigating adaptation times to new climates as they overlook the interaction of occupants with controls and the building. While it may be possible for people to adapt to new indoor conditions, if they are able to modify their environment they may instead continue to match their environment to their preferences over the long term.

Table 2: Mean and standard deviation of indoor air temperature grouped by climate of previous residence.

	Indoor air temperature T_a (°C)					
	November		**January**		**March**	
	mean	**σ**	**mean**	**σ**	**mean**	**σ**
Category A	22.6^{i}	1.3	22.7^{ii}	1.6	23.4	1.6
Category An	24.7^{i}	1.4	25.1^{ii,iii}	1.7	25.4	2.0
Category B	23.7	1.2	23.5^{iii}	1.5	24.0	1.4

$^{i,\,ii,\,iii}$ indicates statistically significant difference between groups.

3.2. Comfort temperatures

Figure 5 shows the distribution of comfort temperatures, calculated using the Griffiths method grouped by climate of previous residence. These results are also summarised in **Table 3**. The roman numerals represent statistically significant differences in comfort temperature determined by one way ANOVA (with Tukey's HSD post-hoc test). Category B is found to have a significantly higher mean comfort temperature than Category A in the first (1.7°C) and second (2.2°C) survey conducted in October and December, respectively. Due to non-normality of the data, ANOVA analysis could not be performed on the February or April surveys. On average, the comfort temperatures of Category A subjects were lower than the other two groups and well within EN15251 design values. While the comfort temperatures fluctuate slightly over time, there are no significant differences between surveys in any group.

3.3. Comparison of preferred and actual temperature

Based on the principle of adaptive thermal comfort, it is expected that indoor air temperature is closely related to comfort temperature. This assumes that individuals take appropriate actions (e.g. opening windows, turning on radiators) to maintain comfort. **Figure 6** shows the relationship between mean indoor air temperature across the three selected monitoring periods and mean comfort temperature across all four surveys. The grey reference line corresponds to the case of 'perfect' adaptation, where the indoor temperature equals the occupant's comfort temperature. There is a significant correlation (r = 0.58) between the two values when considering the whole data set (not considering climate category) which supports the assumption of the adaptive principle. Category A, long term UK residents showed the highest level of correlation (r = 0.65) with Category An also demonstrating reasonably close correlation (0.55). Category B, however, showed very weak correlation (r = 0.28). This indicates that they are the least able to maintain comfortable conditions.

A higher degree of correlation in Category A supports a key premise of adaptive comfort theory as it indicates that those most accustomed to the local conditions, climatic and cultural, are best able to achieve comfort. Many of the Category An participants have air temperatures

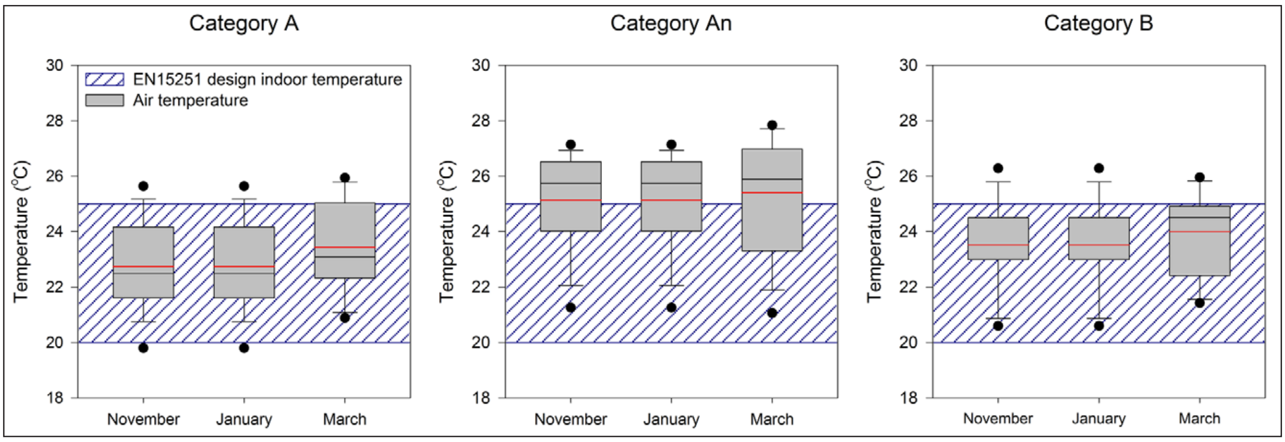

Figure 3: Monitored indoor air temperature for the three selected periods grouped by climate of previous residence.

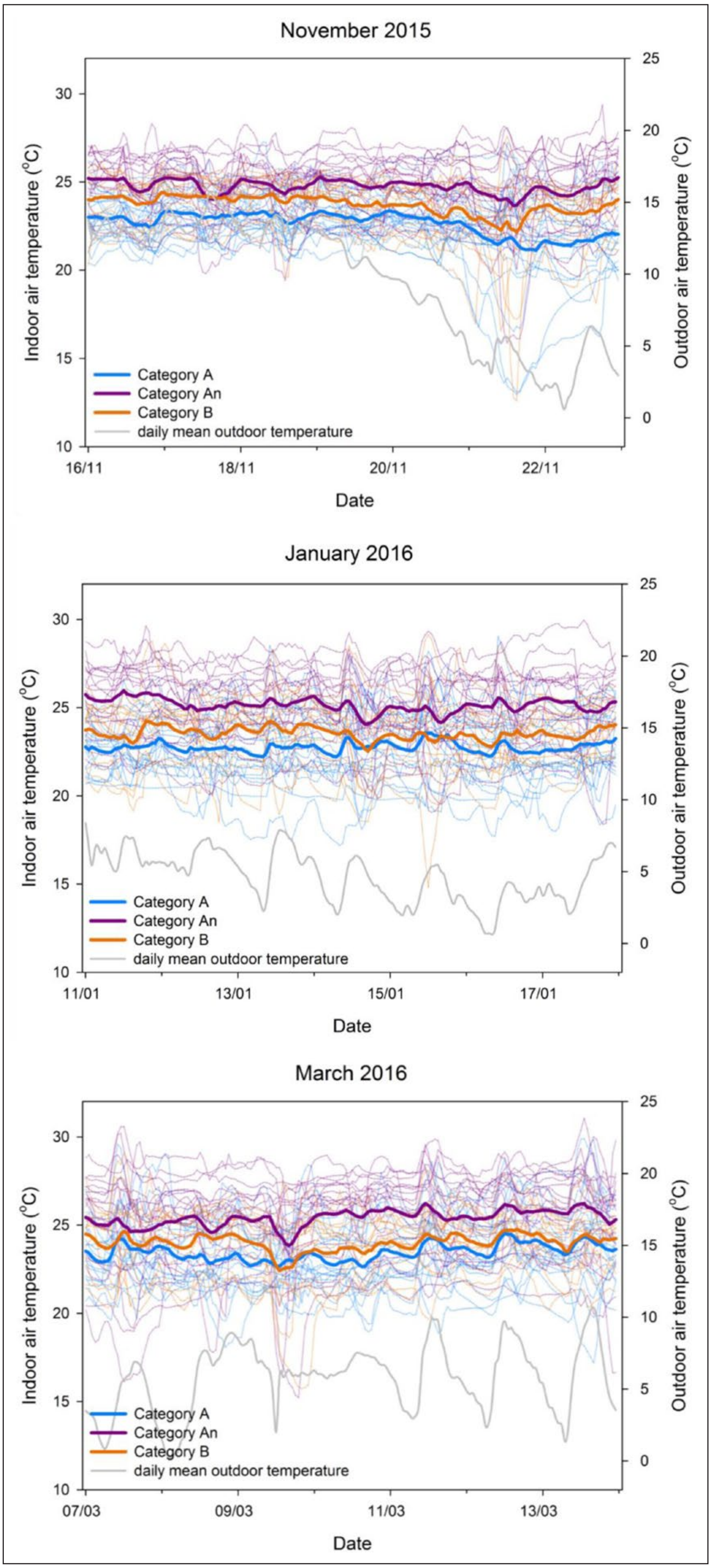

Figure 4: Hourly averaged indoor air temperature (left axis) for each accommodation unit for three one-week periods grouped by climate of previous residence. The hourly averaged ambient temperature is shown on the right axis.

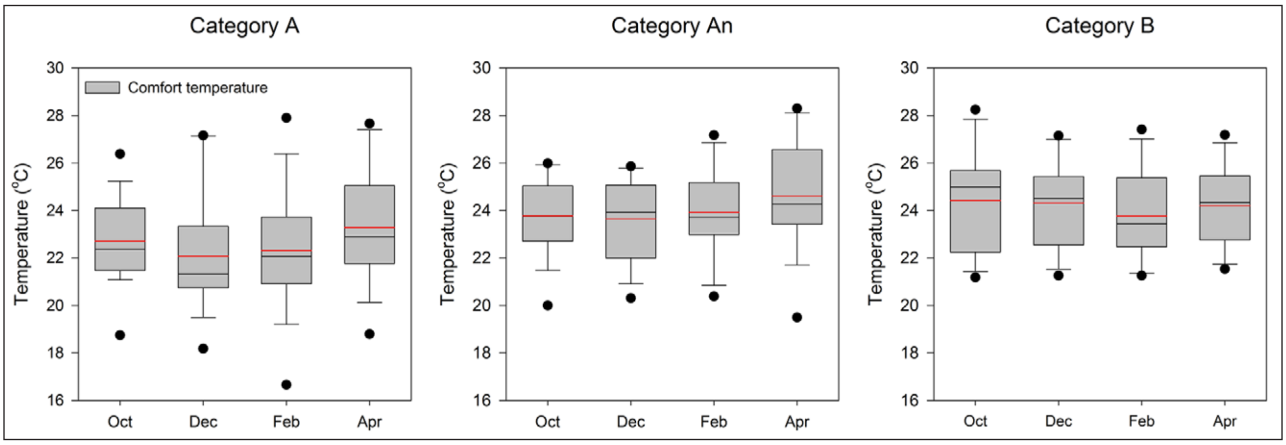

Figure 5: Comfort temperature for each survey grouped by climate of previous residence.

Table 3: Comfort temperatures calculated using the Griffiths method grouped by climate of previous residence.

	Comfort temperature T_{com} (°C)							
	October		December		February		April	
	mean	σ	mean	σ	mean	σ	mean	σ
Category A	22.7[i]	1.8	22.1[ii]	2.4	22.3	2.6	23.3	2.4
Category An	23.8	1.6	23.6	1.7	23.9	1.8	24.6	2.2
Category B	24.4[i]	2.2	24.3[ii]	1.8	23.8	1.9	24.4	1.7

[i, ii] indicates statistically significant difference between groups.

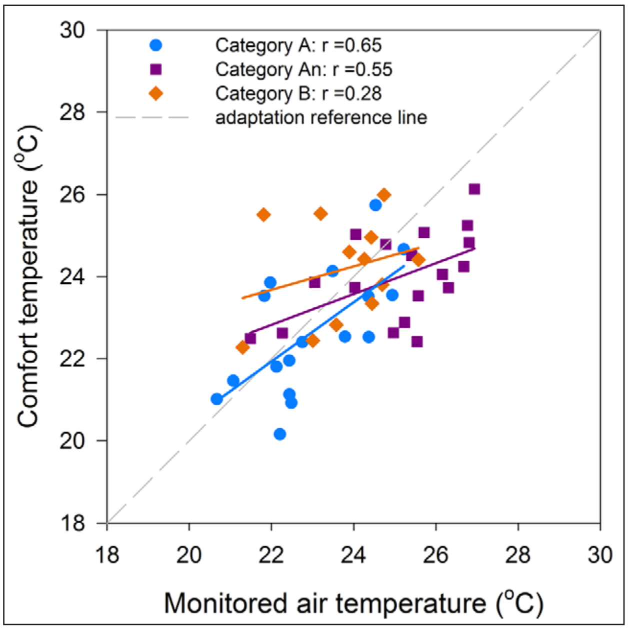

Figure 6: Relationship between participant's mean comfort temperature across the four surveys and mean indoor air temperature for the three monitoring periods. The correlation coefficient (r) for the whole data set is 0.58.

higher than their comfort temperature. This provides further evidence that heating controls are being used in a similar way to the district heating systems of their home country which in this context is compromising thermal comfort. Weak correlation between comfort temperature and air temperature in Category B may be due to a lack of familiarity with the new conditions they experience, especially indoor heating systems, with only 17% having had heating in their previous residence.

4. Conclusions

This paper presented results from a 6-month field study investigating the relationship between thermal experience and adaptation to a new climate. There were significant differences found in indoor air temperature between climate categories in 2 out of the 3 monitoring periods, with long term UK residents' (Category A) being lower in both instances. Participants from cold climates not including the UK (Category An) had consistently high indoor air temperatures which is likely to be due to being accustomed to high levels of central space heating. This highlights the importance of indoor climate experience in determining long term thermal preference and behaviour. Category B (warm climates) participants were found to have a higher mean comfort temperature than Category A in 2 out of the 4 thermal comfort surveys. Additionally, neither the Category An or B groups changed comfort temperature from one survey to the next indicating that no significant adaptation to the new climate took place during the investigated period of 6 months. This shows that, unlike climate chamber experiments, where acclimation may take place within 1–2 weeks (van der Lans et al. 2013; Pallubinsky et al. 2017), in real environments the duration of adaptation appears to be much longer, if at all.

Comparison of indoor air temperature and comfort temperature demonstrated that Category A had the highest level of correlation (r = 0.65). This supports the principles of adaptive thermal comfort in that those most accustomed to the environment, are most able to achieve comfort. Category An participants had reasonably high correlation (r = 0.55) but with higher indoor air temperatures compared to comfort temperatures which may be explained by space heating provision with limited individual control in their previous residence. Category B participants showed very weak correlation between comfort temperature and air temperature, indicating that this group were least able to control their environment to suit their preferences.

The findings of this study are likely to have implications for the energy use of buildings of this type since space heating is used in unexpected ways. However, it also presents opportunities for easing the transition to a new indoor environment for occupants. In particular, it is clear that occupants from warm climates, typically unfamiliar with space heating, would benefit from guidance on the heating controls. This is also true of some participants from cold climates who may be accustomed to space heating but not controls at the individual level. The relationship between comfort temperature and air temperature requires further investigation since the direction of causation is unclear. Either way, this could be used in aiding the transition to a new climate. This could be by helping occupants to match their comfort temperature to typical indoor environments in their new setting or by adjusting the design, operation and management of the building to provide them with their most familiar conditions. An example of this could be to place occupants who are expected to have higher comfort temperatures on the facades of a building which receive the highest solar gain.

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Competing Interests

The authors have no competing interests to declare.

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