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A Study of Thermal Mavericks in Australia

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Abstract

The research presented in this paper was conducted in order to test whether the thermal preferences of occupants in *low energy* houses are influenced by their environmental values. This was done through a thermal comfort study and Environmental Attitudes Inventory (EAI) of 40 *low energy* households located within two very different climates, cold temperate and hot humid, in Australia. The results show that the occupants of these dwellings considered conditions comfortable outside of the accepted adaptive thermal comfort limits and suggest that the conditions people find acceptable may be a function of their underlying environmental values. These results suggest that greater acknowledgement of atypical preferences in the mandatory assessment of building thermal performance is needed. The preliminary analysis presented in this paper is of the first six months of data collected in two cohorts of these 'thermal maverick' households (full data collection will cover approximately 12 months).

Keywords: thermal preference, adaptive model, environmental concern, residential buildings

1. Introduction

The field of thermal comfort research is in a transition period with many experts questioning the relationship between socio-cultural influences, and response to thermal environments (Nicol et al, 2012; Roaf et al, 2010; Chappells & Shove, 2005). This is particularly relevant in residential buildings where there is a more direct relationship between the occupants' perception of their thermal environment and their opportunity for adaption. In an observation on the state of thermal comfort research, Hitchings (2009) suggests that studying the '*thermal mavericks … could help make the strongest case against the further spread of ambient standards'* (pg 92). The hypothesis underlying the research presented in this paper is that occupants of houses traditionally perceived to be *low energy*, are one such group of 'thermal mavericks', demonstrated by their expression of comfort at more extreme temperatures than predicted as acceptable by the widely used ASHRAE adaptive model of thermal comfort (ASHRAE, 2013). Furthermore, the paper presents the argument that this may be explained by the occupants' level of environmental concern.

Despite interest in the literature for exploring the relationship between environmental attitudes and thermal preference (de Dear, 2004), no known studies have investigated this issue using both a psychological measure and comfort votes surveys. Australian studies that touch on parts of this topic include a qualitative investigation into the socio-cultural context of thermal comfort in a work place (Healey & Webster-Mannison, 2012); a quantitative comparison of the environmental attitudes and utility use between eco-village and standard developments (O’Callaghan et al, 2012) and a post occupancy study of two office buildings supplemented with an environmental attitudes measure based on the New Environmental Paradigm (NEP) (Deuble & de Dear, 2012). The findings of all three of these studies support the continued investigation of this relationship; Healey & Webster-Mannison reporting on the importance of cultural and contextual factors on comfort-related adaptions; O’Callaghan et al (2012) demonstrating a correlation between pro-environmental attitudes and lower energy use; and Deuble & de Dear (2012) establishing a link between pro-environmental attitudes and the ‘forgiveness factor’.

Building or buying a *low energy* home could be considered conspicuous ‘environmental’ consumption, where some aspect of the occupant’s value system is displayed through the choices they make about built form, design and construction (Mazar & Zhong, 2010). A well-established example of this is dwellings incorporating earth construction walls (pise, adobe and compressed earth blocks). Occupants of this type of dwelling have previously been linked to higher levels of eco-centric attitudes and energy saving behaviours (Casey & Scott 2006; Daniel & Williamson, 2011); as well as considerable anecdotal evidence that occupants of earth buildings value a low-impact lifestyle (Rael, 2009; Easton, 1996; Dethier, 1981). A second, but almost more intrinsic, example is dwellings that are designed to be naturally ventilated, particularly in hot humid climates. While not as easy to define as earth buildings, these dwellings offer a similar expression of an individual’s choice to ‘experience the climate' not to rely on artificial cooling for comfort. The capacity for reduced energy consumption of this type of household is intuitive but also firmly supported by the literature (Kordjamshidi, 2011; Candido et al, 2010; Gill et al, 2010).

This research investigates these two distinct forms of housing in two very different climates; dwellings incorporating earth construction elements in a cold temperate climate (Melbourne, Australia), and naturally ventilated houses in a hot humid climate (Darwin, Australia). These perceived *low energy* dwellings represent a definable cohort for investigation, as it is likely that the occupants of these houses have higher levels of environmental concern than the general population; embodied in their very decision to live in these types of housing.

In Australia, the assessment of houses to demonstrate compliance with building code energy efficiency requirements relies on a computer simulation program which determines a “star rating”. While the comfort range settings in this software, *AccuRate*, are not the same as suggested by the ASHRAE adaptive model, they are based on an understanding that acceptable conditions vary with the climate zone. These comfort settings determine heating and cooling energy loads which are the basis for the star rating and, ultimately, whether or not the design obtains building approval.

It is noted that the current ASHRAE adaptive model is based on data from non-residential buildings and its application in residential buildings requires further testing; nonetheless, a recent project uses this model to analyse the data from 60 houses in Sydney, Adelaide and Brisbane (Saman et al, 2013). The authors found that acceptable indoor temperatures in the study houses in summer fit within the acceptable limits as predicted by the adaptive model. Peeters et al (2009) also argues that an adaptive model of thermal comfort is likely the most appropriate approach for residential buildings. However, it is hypothesised in this research that current comfort ranges, either in *AccuRate* or based on the current adaptive model, do not necessarily account for the thermal preferences of occupants in *low energy* dwellings. Few known thermal comfort studies have been conducted in residential buildings in Australia, let alone in *low energy* dwellings, resulting in the potential for inappropriate application of thermal comfort standards.

2. Methods

Forty households were recruited in late 2012, early 2013. The households were required to either be living in a dwelling incorporating earth construction walls (mud brick, rammed earth) in a cold temperate climate or operating their home as partially or wholly naturally ventilated in a hot humid climate. It was expected that the thermal conditions and thermal preferences of the occupants within these buildings would represent two extremes when compared to 'typical' conditions (e.g. those described by the ASHRAE adaptive model). All households were 'self-selecting'; responding to advertisements in a local paper or through material (websites, newsletters) circulated by interest groups (*Earth Building Association Australia*, *Nillumbik Mudbrick Association* and *CoolMob*). For statistical consistency the earth building households selected were all located in Nillumbik Shire, Victoria, Australia; while the naturally ventilated households were all located within Darwin, Northern Territory, Australia.

2.1. Meteorological and indoor environment data and equipment

The Nillumbik Shire is located north-east of Melbourne, Victoria and has the Köppen climate classification 'Csb'; Mediterranean climate, dry warm summer, mild winter. The climate has four distinct seasons. Average annual rainfall recorded at the closest Bureau of Meteorology (BOM) weather station, Viewbank (Station number 086068, latitude 37.74 ºS, longitude 145.10 ºE), is 680.3mm. The rainfall is fairly evenly distributed throughout the year with the wettest months being November and December and the driest January and March. Mean daily maximum temperatures range from 13.9 ºC in July (winter) to 27.7 ºC in January (summer), while mean daily minimum temperatures range from 5.8 ºC in July to 14.6 ºC in February. Humidity remains moderate throughout the year ranging from a mean 9am relative humidity of 86% in winter to a mean 3pm relative humidity of 43% in summer (BOM, 2013).

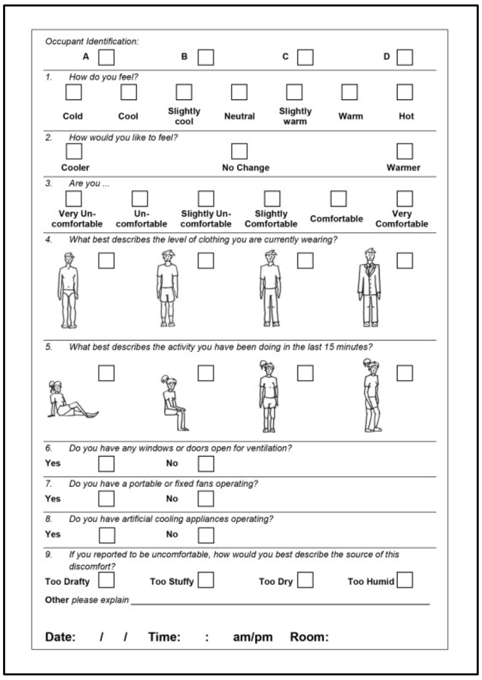
Darwin is located in the Northern Territory and has the Köppen climate classification 'BSh'; hot sub-tropical steppe. The climate has three main seasons; the build-up, the wet (monsoon) and the dry. Average annual rainfall recorded at the closest BOM weather station, Darwin Airport (Station number 014015, 12.42 ºS, longitude 130.89 ºE), is 1726.5mm. The majority of rainfall is received in the monsoon period through January, February and March. The driest period is through June, July and August where very low amounts of rainfall are recorded (1.9mm, 1.2mm and 5.0mm respectively). Mean daily maximum temperatures have a narrow range from 30.5 ºC in July (the dry) to 33.3 ºC in November (the build-up/the wet), while mean daily minimum temperatures have a similarly narrow range from 19.3 ºC in July to 25.3 ºC in November and December. Humidity is highest in the wet season with a mean 9am relatively humidity of 83% (February) and lowest in the dry season with a mean 3pm relatively humidity of 37% (July) (BOM, 2013).

For this research weather data (precipitation, air temperature, dew point, relative humidity, wind speed, direction and gust, and barometric pressure) were sourced from the closest BOM weather stations to the respective case study areas (Viewbank and Darwin Airport) for the monitoring period.

In general, data collection meets the requirements of a Class-II field study and the requirements of ASHRAE 55-2013 (ASHRAE, 2013) for data collection. Two HOBO U12-013 Data Loggers were installed in each house to measure and record air temperature, globe temperature and relative humidity. In addition, an anemometer sensor was included in the Darwin equipment to monitor indoor air movement. One logger was located in the household's primary living area and a second logger was placed either in a subsequent living area or the main bedroom. The loggers were located away from heat sources, out of direct sunlight and, where possible, in a central location within the room at approximately 1.1-1.7m above floor level.

2.2. Comfort vote survey

A paper based comfort vote survey in booklet form was distributed to all households, Figure 1; residents above the age of 18 years old were invited to fill them out on a daily basis. Three widely used subjective measures of thermal comfort were included; sensation 1=Cold to 7=Hot (ASHRAE, 2013); preference 1=Cooler, 2=No change, 3=Warmer (McIntyre, 1982) and; comfort 1=Very uncomfortable to 6=Very comfortable (Brager et al, 1993). The survey also asked the respondents to report their clothing level, activity, and window, fan and artificial heating/cooling operation. A final question asked respondents to identify any source of discomfort not directly related to temperature (i.e. draft, stuffy, dry, humid sensation). The respondents were instructed to complete the survey within the rooms that the loggers were situated. The surveys were collected after six months and manually entered into *Excel* spreadsheets with the time of filling out the survey form matching the corresponding time in the monitored data.


Occupant Identification:
A ☐ B ☐ C ☐ D ☐

1. *How do you feel?*
Cold ☐ Cool ☐ Slightly cool ☐ Neutral ☐ Slightly warm ☐ Warm ☐ Hot ☐

2. *How would you like to feel?*
Cooler ☐ No Change ☐ Warmer ☐

3. *Are you ...*
Very Un-comfortable ☐ Un-comfortable ☐ Slightly Un-comfortable ☐ Slightly Comfortable ☐ Comfortable ☐ Very Comfortable ☐

4. *What best describes the level of clothing you are currently wearing?*
☐ ☐ ☐ ☐

5. *What best describes the activity you have been doing in the last 15 minutes?*
☐ ☐ ☐ ☐

6. *Do you have any windows or doors open for ventilation?*
Yes ☐ No ☐

7. *Do you have a portable or fixed fans operating?*
Yes ☐ No ☐

8. *Do you have artificial cooling appliances operating?*
Yes ☐ No ☐

9. *If you reported to be uncomfortable, how would you best describe the source of this discomfort?*
Too Drafty ☐ Too Stuffy ☐ Too Dry ☐ Too Humid ☐
Other *please explain* ____

Date: / / Time: : am/pm Room:

Figure 1 Comfort vote survey

2.3. Environmental Attitude Inventory (EAI) survey

An EAI tool developed by Milfont & Duckitt (2007; 2010) was used to gauge the occupants' level of environmental concern based on 12 attitudinal scales, Table 1. The EAI asks respondents to indicate their extent of agreement or disagreement with 24 statements on a 7-point Liket scale. The scores given define two higher-order factors of environmental attitude; 'preservation' and 'utilisation' (Milfont & Duckitt, 2007). Seven of the 12 scales contribute to an overall preservation score, while five contribute to an utilisation score. The preservation dimension broadly reflects biocentric (ecocentric) concern (conservation and protection), while the utilisation dimension reflects anthropocentric concern (utilisation of natural resources) (Milfont & Duckitt, 2010).

Surveys were manually coded and entered into an *Excel* spreadsheet. Mean preservation and utilisation scores were calculated for each case study cohort. Two control samples (for the corresponding locations; north-eastern suburbs of Melbourne and Darwin) were sourced using a panel provider; *Online Research Unit*. The survey was administered online and, except for subsequent demographic questions, was identical to that conducted with the case study households.

Table 1 Twelve attitudinal scales for use in EAI survey (Milfont & Duckitt, 2007)

Scale label	**Preservation**	**Utilisation**
01 Enjoyment of nature	*	
02 Support for interventionist conservation policy	*	
03 Environmental movement activism	*	
04 Conservation motivated by anthropocentric concern		*
05 Confidence in science and technology		*
06 Environmental threat	*	
07 Altering nature		*
08 Personal conservation behaviour	*	
09 Human dominance over nature		*
10 Human utilisation of nature		*
11 Ecocentric concern	*	
12 Support for population growth	*	

3. Results

3.1. Indoor thermal conditions

Internal prevailing conditions when votes were recorded during the monitoring period are presented in Figure 2 and Figure 3 for the Melbourne and Darwin households. Accepted comfort zones for the relevant periods are also shown (ASHRAE, 2013, Appendix B). In the Melbourne dwellings, conditions were largely cooler than the comfort zone, while in Darwin, the conditions were largely warmer. The average air speed measured at the time of voting in the Darwin households was 0.21m/s.

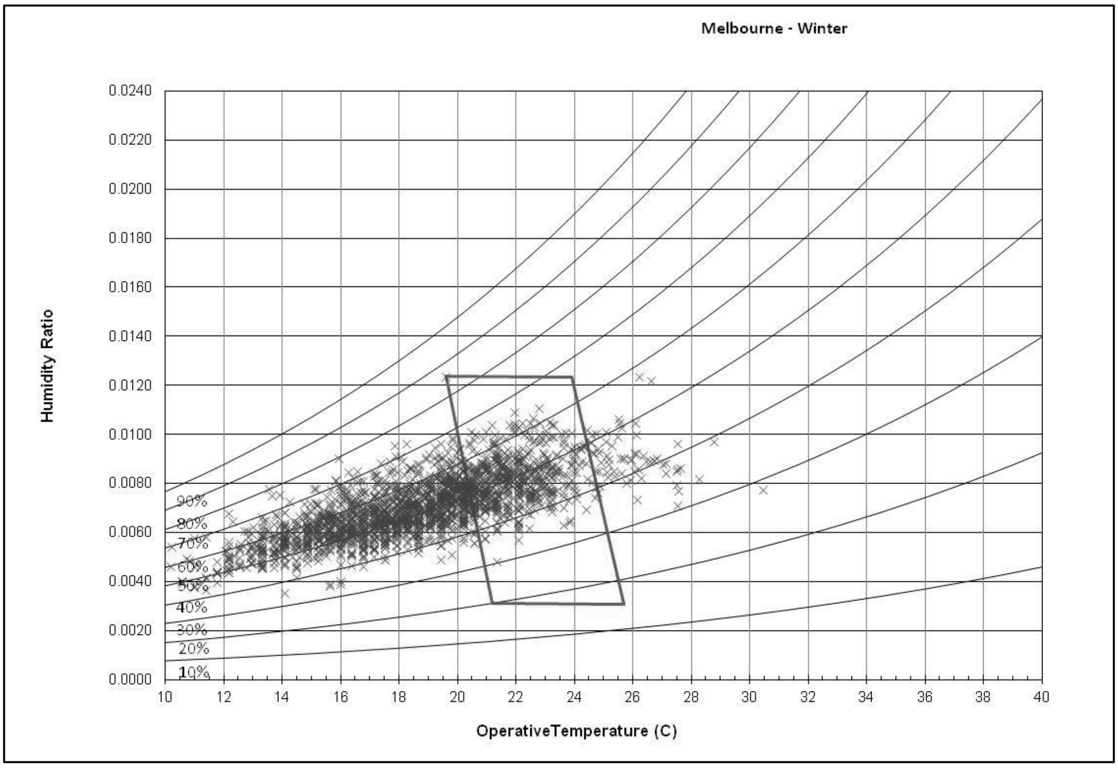


Figure 2 Comparison of the accepted winter comfort zone and the indoor operative temperature and humidity at the times comfort votes were recorded for Melbourne on the psychometric chart

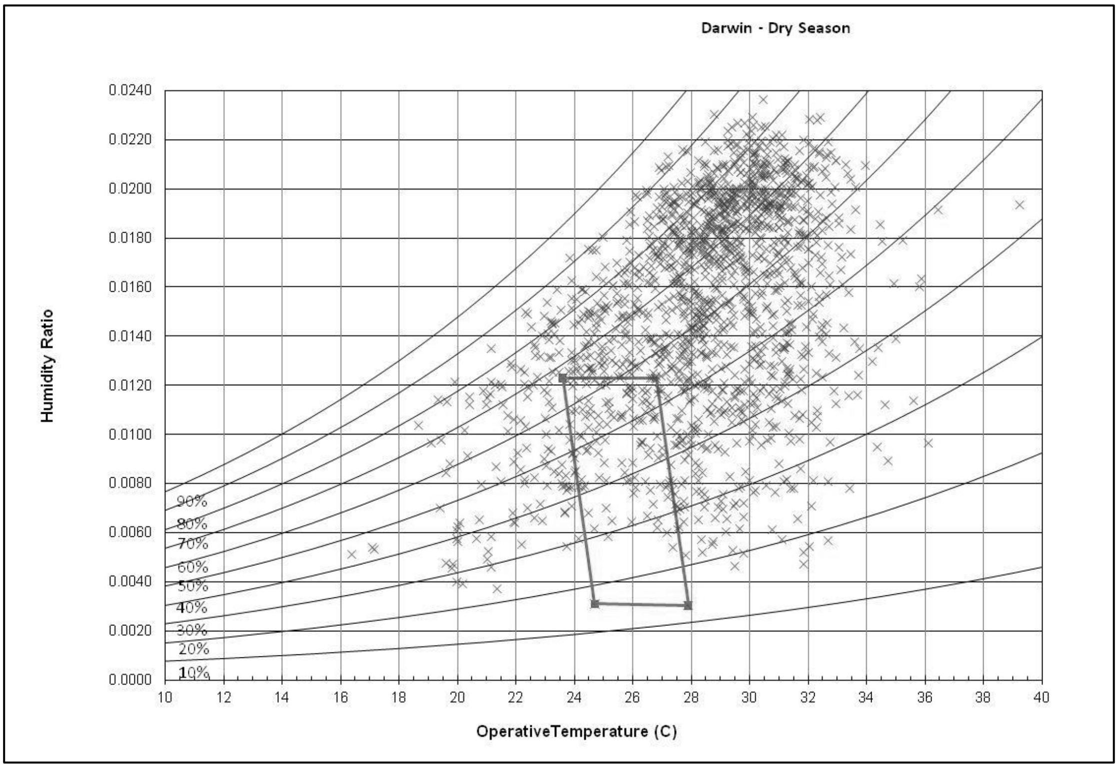


Figure 3 Comparison of the accepted dry season comfort zone and the indoor operative temperature and humidity at the times comfort votes were recorded for Darwin on the psychometric chart

3.2. Thermal comfort survey

Two-thousand thermal comfort survey responses were collected from the Melbourne households between March and August 2013, representing the autumn and winter season; while fifteen-hundred responses were collected from the Darwin households between June and December 2013, representing the dry season and monsoon build up.

Cross-tabulation of the sensation and preference votes of the Melbourne cohort show that the most common vote was ‘neutral’ with a preference for ‘no change (32.8%), Figure 5. Interestingly the subsequent highest percentages of votes recorded by the Melbourne cohort were for ‘slightly warm’ (14.8%), ‘warm’ (14.5%) and ‘no change’ indicating a preference for warmer sensation. A proportionally high percentage of votes at ‘slightly cool’ and ‘warmer’ (13.8%) similarly support the preference for ‘neutral’ or warmer sensation.

The cross-tabulation of the sensation and preference votes from Darwin reveal that ‘neutral’ and ‘no change’ was the most regularly recorded vote (41.8%), with high percentages also recorded at ‘slight cool’ (11.9%) and ‘slightly warm’ (18.4%) and ‘no change’. Noticeable is the percentage of votes recorded at ‘slightly warm’ with a preference to be ‘cooler’ (7.8%) when observed in conjunction with the percentage of votes recorded at ‘slightly warm’ and ‘no change’; the distribution of votes signifying the limit of preferred conditions.

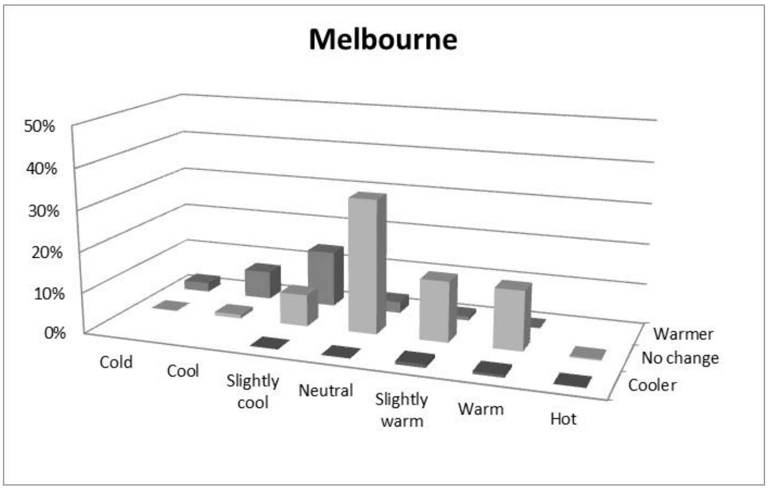


Figure 4 Sensation vs preference votes for the Melbourne cohort for the period of March - August 2013

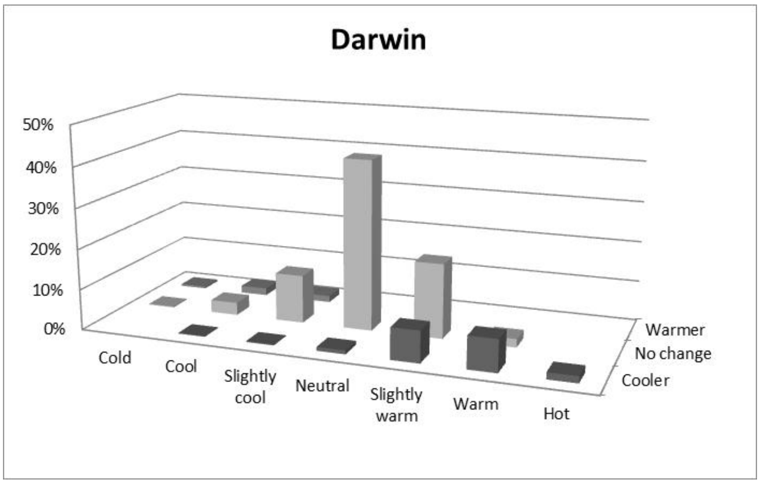


Figure 5 Sensation vs preference votes for the Darwin cohort for the period of June - December 2013

The cross-tabulation of the sensation and comfort votes, Figure 6, from the Melbourne cohort indicate that the highest percentages of 'comfortable' votes are recorded at 'neutral' (26.9%), 'slightly warm' (12.6%) and 'warm' (10.3%), again supporting the occupants' preference for warmer than neutral sensation; similarly echoed by the percentage of 'slightly cool' (9.1%) votes eliciting a 'slightly uncomfortable' response.

The sensation and comfort votes recorded by the Darwin cohort were predominantly at 'slightly cool' (7.6%), 'neutral' (30.2%), 'slightly warm' (11.5%) and 'comfortable', Figure 7. The votes show that the occupants rarely report to being uncomfortable when 'slightly cool' (1.0%), 'cool' (1.14%) and 'cold' (0.47%), rather, discomfort is recorded at 'slightly warm' (7.1%), 'warm' (6.89%) and 'hot' (1.54%), likely also due to relative humidity levels.

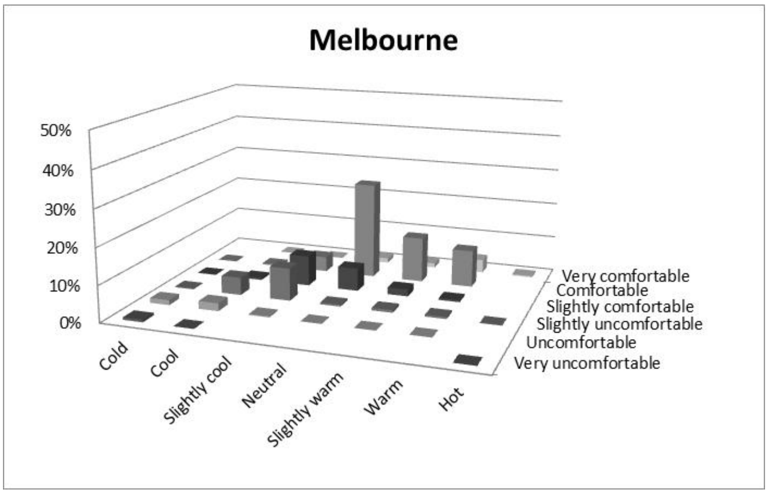


Figure 6 Sensation vs comfort votes for the Melbourne cohort for the period of March - August 2013

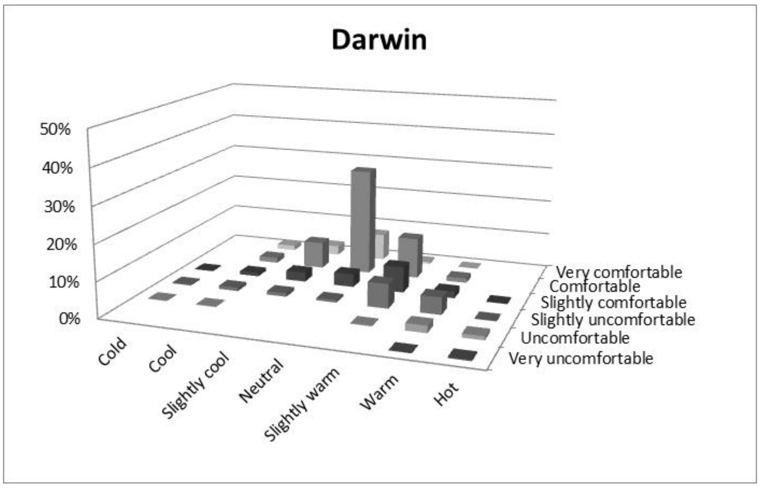


Figure 7 Sensation vs comfort votes for the Darwin cohort for the period of June - December 2013

Cross-tabulation of the Melbourne comfort and preference votes show that approximately half on the votes recorded were for 'no change' and 'comfortable' (52.0%). Notably, however, the second largest proportion of votes was reported when preference was to be 'warmer' at 'slightly uncomfortable' (13.2%), suggesting that cooler conditions were the primary source of discomfort.

The Darwin comfort and preference cross-tabulation indicates that generally occupants voted ‘no change’ at ‘slightly comfortable (12.8%), comfortable (49.2%) and very comfortable (12.3%), however it is interesting to note that some of the votes at slightly uncomfortable (3.1%) still had no preference to change. The highest percentage of votes recorded at slightly uncomfortable (10.0%) had a preference to be cooler, again indicating that warmth was the source of discomfort.

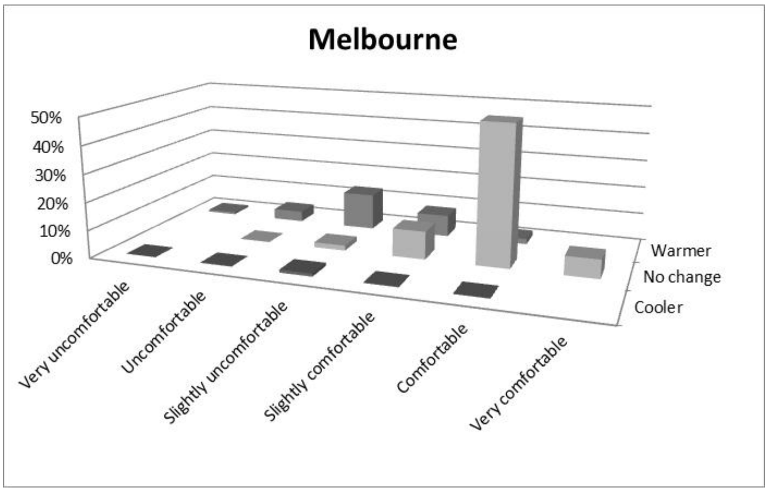


Figure 8 Comfort vs preference votes for the Melbourne cohort for the period of March - August 2013

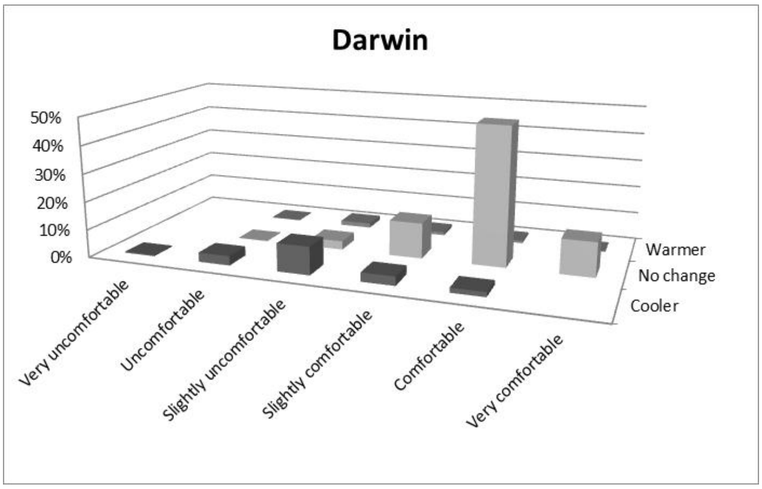


Figure 9 Comfort vs preference votes for the Darwin cohort for the period of June - December 2013

3.3. Comparison with the ASHRAE adaptive model

In order to compare the thermal comfort votes of the case study households to that of a *typical* population, instances where the respondents voted 'slightly cool, ‘neutral’, ‘slightly warm’ and ‘no change’ (SENS345/PREF2) were plotted against the ASHRAE 55 (2013) adaptive 80% and 90% upper and lower comfort limits, see Figure 10. These votes are taken to represent comfort temperatures of the two cohorts.

In general, the Melbourne cohort reported to be comfortable at lower temperatures than the ASHRAE adaptive model predicts as acceptable, while the Darwin cohort report to be comfortable at higher temperatures. The aggregate slope of the case study data trend line (0.63) is steeper than the trend line of the adaptive comfort model (0.31), demonstrating considerable difference between the thermal preference of the cohort studied and the adaptive neutral temperatures. This finding is comparable to results presented in Williamson et al (1995), where the trend line slope of comfort data from Australian households was 0.58, suggesting that these finding may be more representative for residential buildings.

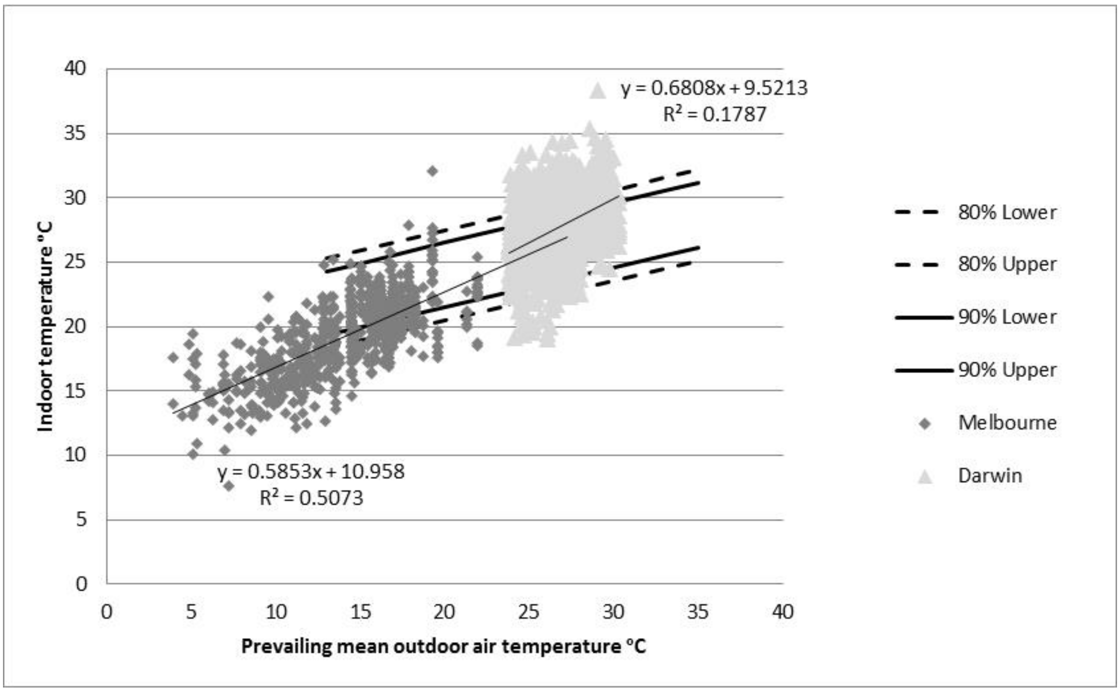


Figure 10 Votes when occupants report to be SENS345/PREF2, where prevailing mean outdoor air temperature is based on a 7-day running weighted mean of daily temperatures

The percentages of the SENS345/PREF2 votes that are outside of the ASHRAE upper and lower 80% and 90% limits are given in Table 2, the 80% and 90% adaptive limits are assumed to continue below 13 ºC (Van der Linden et al, 2006). A substantial proportion of the SENS345/PREF2 votes are outside of the adaptive 80% and 90%; indicating a preference for a wider range of thermal conditions than the ASHRAE adaptive model describes as comfortable.

Table 2 Percentage of votes where occupants report to be 'slightly cool', 'neutral', 'slightly warm' and want 'no change' outside of the ASHRAE Adaptive 80% and 90% upper and lower limits

Cohort	**Percentage outside 80% limits**	**Percentage outside 90% limits**
Melbourne	41.18%	54.94%
Darwin	26.57%	46.96%

The cooler *comfort* temperature of the Melbourne cohort and the warmer *comfort* temperature of the Darwin cohort are apparent when the monthly $T_{SENS345PREF2}$ for each location is calculated based on the corresponding regression equation shown in Figure 10, where x is the monthly mean outdoor air temperature, and plotted on a Nicol graph (Nicol & Humphreys, 2002) using the ASHRAE adaptive formula to obtain T_{comf}, equation (1), see Figure 11 and Figure 12.

$$Tcomf = \ 0.31\,\bar{T}o + \ 17.8 \quad (1)$$

where $\bar{T}o$ is the monthly mean outdoor air temperature.

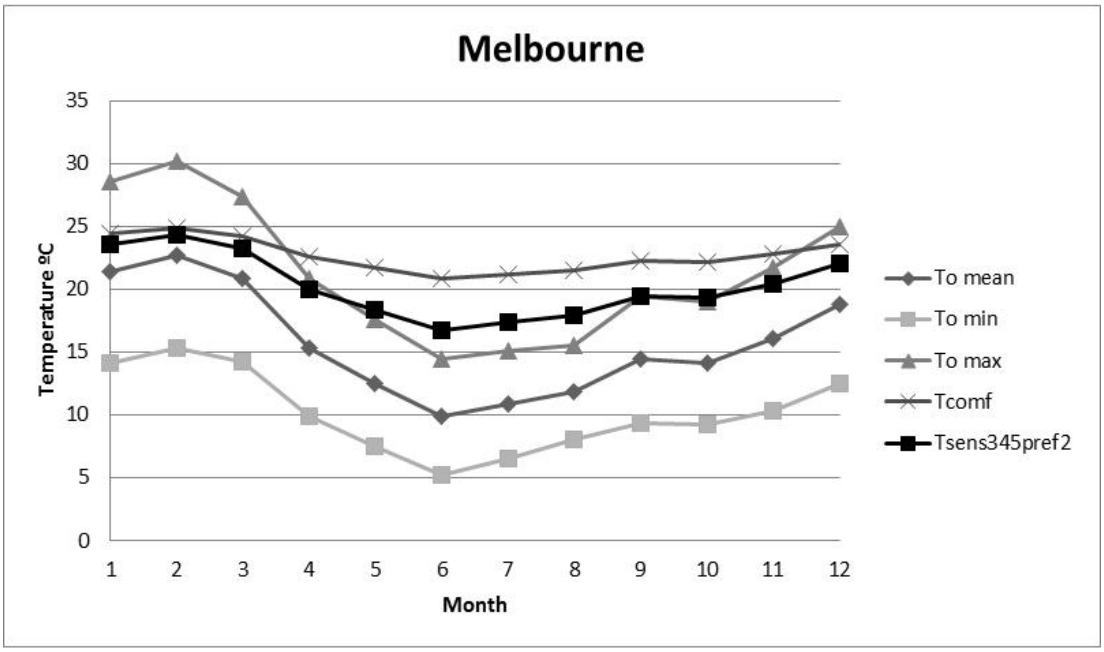


Figure 11 Comparing T_{comf} with $T_{comf\,sens}$ for Melbourne using 2013 meteorological data

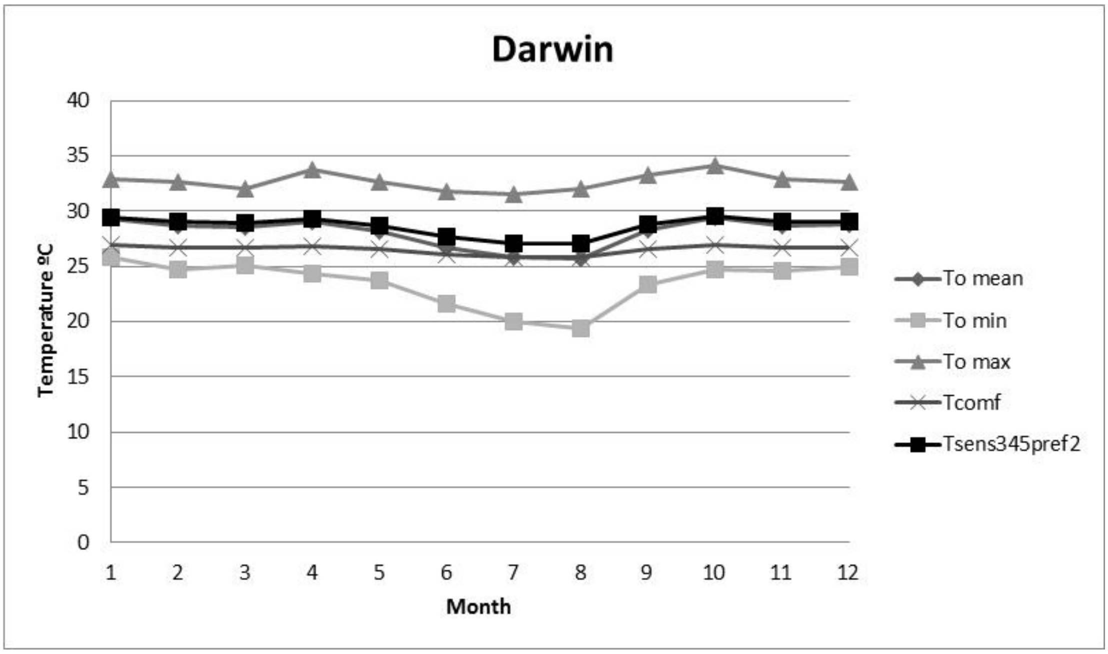


Figure 12 Comparing T_{comf} with $T_{comf\,sens}$ for Darwin using 2013 meteorological data

3.4. Environmental Attitudes Inventory (EAI) survey

All adult occupants in the case study households were invited to complete the EAI survey; the Melbourne case study group returned 33 completed surveys, while the Darwin case study group returned 27, Table 3. At least one occupant completed the survey in each household. The commercial online panel provider obtained 113 control sample responses from the North-eastern suburbs of Melbourne and 36 from Darwin. The control samples correspond to population size.

Table 3 EAI mean preservation and utilisation scores for case study cohort and control groups

Cohort	Sample	Mean preservation score (standard deviation)	Mean utilisation score (standard deviation)
Melbourne case study cohort	33	5.55 (0.893)	2.99 (0.846)
Melbourne control	113	4.0 (0.460)	4.1 (0.471)
Darwin case study cohort	27	5.90 (0.633)	2.53 (0.749)
Darwin control	36	4.5 (0.900)	3.5 (0.850)

Paired-samples t-tests were conducted in order to compare the mean preservation and utilisation scores of the case study and control groups. The mean preservation scores for both the Melbourne and Darwin case study groups were higher than those of the control samples, indicating a greater level of biocentric concern relating to conservation and protection of the environment. On the other hand, the mean utilisation scores of the two case study groups were lower than the mean utilisation scores of the control sample, demonstrating a lower level of anthropocentric concern relating to the utilisation of natural resources. There was a significant difference in the mean preservation scores for the Melbourne case study sample (M=5.55, SD=0.893) and the Melbourne control sample (M=4.0, SD=0.460); $t(37.09)=9.6057$, $p=<0.0001$. The utilisation scores for the Melbourne case study group (M=2.99, SD=0.846) when compared to the Melbourne control sample (M=4.1, SD=0.471) were also significantly different; $t(37.97)=-7.2176$, $p=<0.0001$. Similarly, there was a significant difference in the mean preservation scores for the Darwin case study sample (M=5.9, SD=0.633) and the Darwin control sample (M=4.5, SD=0.900); $t(60.79)=7.2450$, $p=<0.0001$. The utilisation scores for the Darwin case study group (M=2.53, SD=0.749) when compared to the Darwin control sample (M=3.5, SD=0.850) were again significantly different; $t(59.35)=-4.7994$, $p=<0.0001$. These results suggest that both the Melbourne and Darwin case study groups have higher levels of environmental concern based on its intrinsic value rather than its anthropogenic utility when compared to the general population as represented by the control samples.

It is worth noting that the results presented in this paper align with those reported by O'Callaghan et al (2012); where the preservation (M=5.88, SD=0.59) and utilisation (M=2.65, SD=0.59) scores for the *Ecovillage* study group (n=39) were higher and lower, respectively, than the preservation (M=4.92, SD=0.62) and utilisation (M=3.35, SD=0.61) scores for the *Observatory* control group (n=36). So while this is not a commonly used tool in building science or thermal comfort research we can have some level of confidence in its consistency.

3.5. Household energy use

Whilst not a primary focus of this paper, the long-term energy use of the case study households was investigated in order to confirm that they can be considered as 'low energy dwellings' when compared to typical households in the same location. The average daily electricity consumption per household for the Melbourne cohort was

17.1 kWh, lower than the Nillumbik Shire average; 24.2 kWh (State Government of Victoria, 2013). Similarly, the average daily electricity consumption per household for the Darwin cohort was 14.6 kWh, again lower than the average for the Northern Territory; 24.4 kWh (Power and Water Corporation, 2011). This basic comparison corroborates the anecdotal evidence presented in the literature that these forms of dwellings can be considered as *low energy* forms of housing.

4. Discussion

During the course of analysis it became evident that development of upper and lower limits of comfort is particularly important for the practical application of any thermal comfort research. This prompted an investigation into the formation of the 80% and 90% upper and lower limits of the adaptive comfort model based on Fanger's (1970) PPD index (de Dear & Brager, 1998). Previous studies (Langevin et al, 2013; von Grabe & Winter, 2008) have sought to consolidate the relationship between preference and sensation votes in order to create a stronger model of discomfort.

In order to achieve this using data from the two case study cohorts, the comfort votes were binned by the running weighted daily mean temperature and filtered to exclude votes not at 3 =slightly cool, 4 =neutral or 5 =slightly warm on the ASHRAE sensation scale. Outliers were deleted based on the interquartile range test of the indoor temperatures and the data sets tested for normal distribution using the Shapiro-Wilk test. An *Excel* function was used to return the inverse of the normal cumulative distributions 0.1, 0.2, 0.8 and 0.9 based on the mean and standard deviation of the binned temperatures. Figure 13and Figure 14 show the results for the Melbourne and Darwin data sets.

It is important to note that these boundaries do not represent the same thing as those presented in the ASHRAE adaptive comfort model; but rather, the upper and lower 80 and 90 percentiles of the two cohorts' votes that express satisfaction with the thermal environment. This has been taken to indicate a comfort range. This preliminary description of the thermal preference of the two case study cohorts clearly demonstrates the capacity of occupants to consider a wider range of thermal conditions comfortable with a tentative explanation attributed higher levels of pro-environmental attitudes.

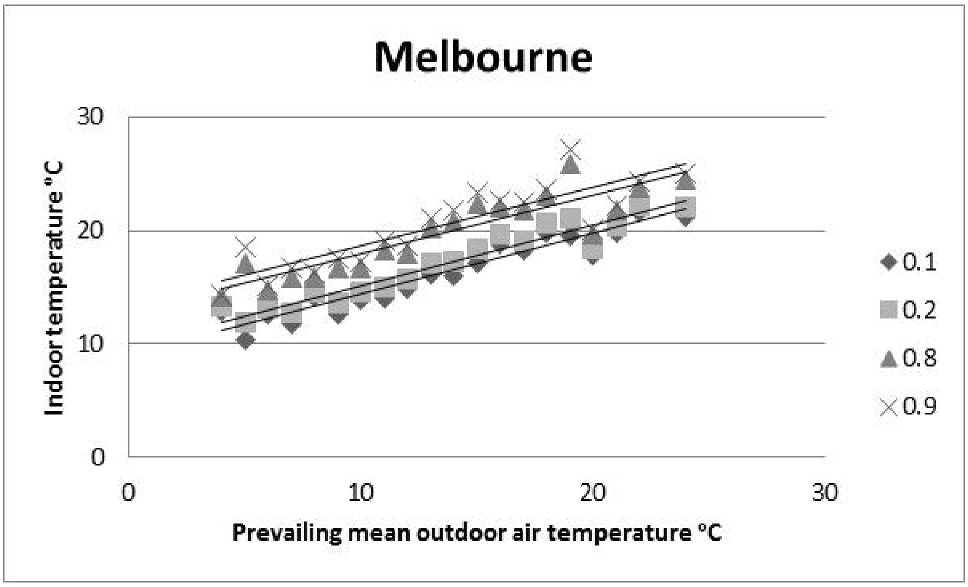


Figure 13 Upper and lower comfort limits based on collected data for Melbourne

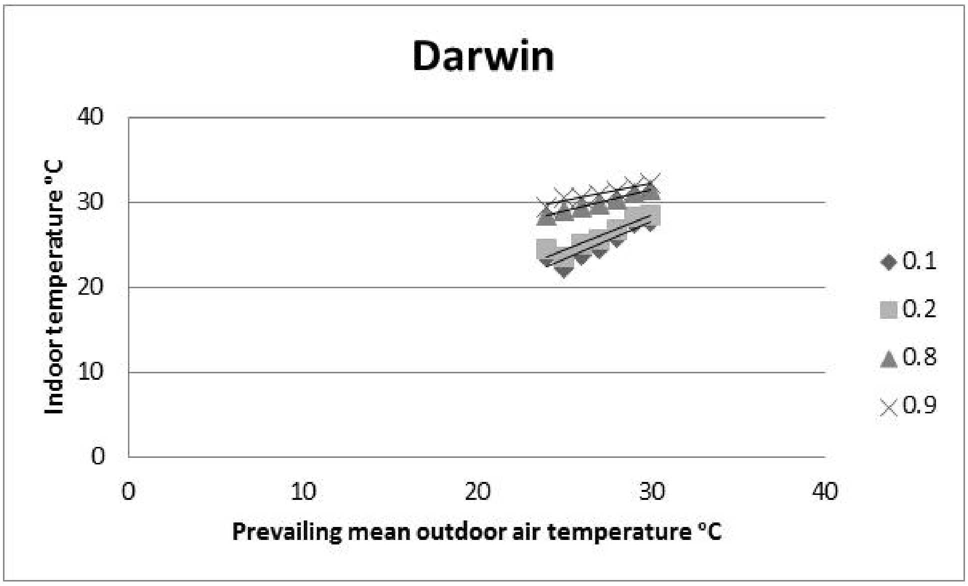


Figure 14 Upper and lower comfort limits based on collected data for Darwin

5. Conclusion

The analysis of preliminary data presented in this paper supports an association between atypical thermal preferences and higher levels of environmental concern in *low energy* houses and demonstrates the value of investigating 'thermal maverick' cases. Both of the cohorts studied, dwellings incorporating earth construction elements in a cold temperate climate and naturally ventilated houses in a hot humid climate, reported to be comfortable at temperatures outside of the ASHRAE adaptive comfort limits and demonstrated higher levels of environmental concern than the control samples. The data collected in this study contributes to a growing understanding of thermal comfort and preference in residential buildings. In addition, the results presented offer an extended way of thinking about adaptive thermal comfort, particularly in a time where boundaries in the provision of thermally comfortable spaces are being reassessed. While principally investigating a potential causal relationship between occupant thermal perception and preference in residential buildings, this basic relationship is also likely to be relevant for a wider range of buildings. It suggests that rather than simplification and standardisation, a wider diversity of comfort conditions should be considered.

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