Field study of the Occupant’s Thermal Preferences for Cooling in Living Rooms Based on Different Set Point Temperatures

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Abstract. The use of an air conditioner (AC) becomes essential in residential buildings, particularly in a hot and humid climate to optimize indoor thermal comfort. To accelerate the process of space cooling, occupants tend to use the lowest set point of the AC thermostat setting to achieve the desired thermal comfort in the indoor environment. A field study was conducted to investigate the occupants’ thermal preferences in experimental living rooms at four AC set point temperatures (16°C, 20°C, 24°C, and 28°C). The indoor thermal environmental measurement and questionnaire survey were conducted on 63 respondents with 252 samples. The results of the thermal sensation vote (TSV) revealed that at the AC set point temperatures of 16°C and 20°C, 38% and 62% of the respondents voted ‘cold’, respectively. Meanwhile, they voted ‘a bit warmer’ for their thermal preference (TP). At the set point temperature of 24°C, 41% of the respondents voted ‘neutral’ for TSV, while 54% voted ‘no change’ for TP. At the same time, for the set point temperature of 28°C, 38% of the respondents voted ‘slightly warm’ for TSV and ‘a bit cooler’ for TP. In short, the respondent might have different thermal preferences even though they were experiencing the same thermal condition. This finding also indicated that there is a limit to how much the AC can provide uniform thermal satisfaction among occupants in the same room with a single control of the set point temperature.

1. Introduction

In a hot and humid climate, a residential environment encounters the challenge to maintain comfortable indoor thermal conditions in a building space. This results from the fact that the building space is always uncomfortable due to high temperature, high relative humidity, and low air movement [1], all of which lead to a condition of thermal discomfort in an indoor space. At present, the use of air-conditioner (AC) is the most effective means for the cooling of an indoor space [2]. Nevertheless, people living in a hot and humid country like Malaysia tend to use the AC by setting it at the lowest set point temperature [3]. The average set point temperature has been found to be 20.8°C, while more than 15% of the respondents
set the temperature to between 16 and 17°C, which is considered the lowest set point temperature [4]. Therefore, the temperature settings are used as a reference and the indoor temperature is somewhere between the AC air temperature and the ambient temperature. However, such a low temperature could overcool the interior space and cause cold discomfort [5]. The overcooling effect is a result of the over-specification of air conditioning systems [6] such as high maximum and minimum airflow rates, set point temperatures, and narrow temperature controls for a space [7]. In contrast, the insufficient insulation of residential buildings could provide poor thermal resistance, which obliges residents to set low target temperatures resulting in very low room temperatures and necessitates the continuous use of AC [8]. The proposed thermostat set point temperature of 24°C for office buildings in Malaysia has not been implemented effectively. This is due to occupants of office buildings in tropical regions who prefer the indoor temperature to be lower than 20°C. This type of preference occurs because of the high daytime outdoor temperature i.e. approximately 32°C [4, 5].

An indoor thermal environment is influenced by the interaction of different climatic conditions within the building spaces, which provides an indication of the level of indoor thermal comfort [1]. Respondents’ responses may vary as individual physiological and psychological acceptances are different despite experiencing the same indoor thermal environment. It would be vital to infer that respondents that are in the same condition of thermal environment and have similarities in age, gender, and metabolic rate might have different thermal acceptances and preferences [10]. The neutral thermal sensation (neither cold, nor hot) is widely used through the application of the ASHRAE Standard 55 seven-point thermal sensation scale to assess thermal comfort [11]. Based on limited data for residential buildings with the AC usage, there is a need for further study related to the respondents’ thermal preferences [10]. This can be studied by determining the AC set point temperature from the minimum to maximum settings with the difference of 4°C. Thus, the objective of the study is to investigate the thermal preference of respondents in the same experimental living room at four different AC set point temperatures ($T_s$) i.e. 16°C, 20°C, 24°C, and 28°C at their respective seating locations.

2. Methodology

2.1. Building information

The measurement was conducted in the experimental living rooms of two universities; Universiti Teknologi Malaysia, Kuala Lumpur (U1) and Universiti Malaysia Pahang, Pekan, Pahang (U2). The U1 experimental living room which is located at the second floor of a two-storey building has an area of 62 m$^2$, equipped with a ceiling cassette AC. Meanwhile, the U2 experimental living room is located at the first floor with an area of 48 m$^2$, equipped with a split unit AC. Figures 1 (a) and 1 (b) show the floor plans of the U1 and U2 experimental living rooms, respectively. The door, windows and blinds of each room were closed during the measurement period. The use of a shading device like a blind for a window affects natural convective and radiant heat transfer into the room. It influences heat transmission and solar heat gain through the window [12]. The respondents must remain seated at the allowable seating locations until each session was completed. They could be seated either on the sofa or on the carpeted floor.
2.2. Respondents
In this study, 43 respondents consisted of 29 males and 14 females from U1, while 20 respondents consisted of 13 males and 7 females from U2. All the respondents were university student volunteers. Only the respondents with good health conditions (i.e. not having a fever, flu or cold, and not on any medication) were allowed to participate in this experiment. During the experimental period, they were free to wear casual clothes and only certain physical activities that can be done in a sedentary manner.

Figure 1: Layout of experimental living room with the notation of allowable seating location and sensors installed (the notation of seating location by the alphabet from A to J, while the tagged of V (Kanomax hot wire anemometer), T1 to T5 (HOBO and TR-77Ui thermo recorder) represents the location of the installed sensors); (a) U1 and (b) U2
i.e. watching a movie or drama, having a slow volume chat, reading, using a smartphone, and sitting quietly, were allowed. Therefore, the metabolic rate was assumed to be 1.0 met for all respondents. Therefore, as each respondent experienced four different thermal conditions, the aggregated data collected were 172 from U1 and 80 from U2. This resulted in a total of 252 samples collected during the period of measurement.

2.3. Indoor climatic parameters
The experiment was conducted during the daytime office hours i.e. from 8:00 am to 5:00 pm, prior to the respondents’ availability during the period from September 2019 until February 2020. All respondents were exposed to each AC set point temperature in a group of four to six persons for 45 minutes. Four indoor environmental parameters were measured at a 10-s interval throughout the experimental period; the measured parameters were the air temperature ($T_a$), globe temperature ($T_g$), relative humidity (Rh), and air speed ($V_a$). All sensors were attached to the custom made pipe stand, shown in Figure 2. They were fixed at the height of 0.7 m above the floor, at the same level with the respondents’ normal seating position in a living room (i.e. on a sofa or on the carpeted floor). The details of each sensor are shown in Table 1. For the AC system control, the room temperature fluctuated at ±0.5°C [13]. The room temperature might be fluctuated slightly with the presence of the respondents, while their seating locations and the low-energy physical activities performed would not affect the measured room temperature.

To conduct the field study, the AC was on at one to two hours before the experiment started. The thermostat was set to the desired case until the measured room temperature reached ±0.2°C. Then a group of respondents came into the room, adapted to the current thermal environment and chose their seating locations within ten minutes. Subsequently, the experiment took place for forty-five minutes. After that, the respondents were required to complete the questionnaires for five to ten minutes and leave the room.

![Figure 2: The setup of sensors; (a) ONSET HOBO and TR-77i thermo recorder and (b) Kanomax Climomaster hot-wire anemometer](image)

| Sensor                  | Parameter measured | Type of Sensor                      | Resolution accuracy and tolerance       |
|-------------------------|--------------------|-------------------------------------|----------------------------------------|
| Thermo recorder U12 – U13 | Air temperature   | External sensor cable tmc1-hd        | 0.03°C ±0.35°C [0 to 50°C]             |
|                         | Globe temperature | External sensor cable tmc1-hd + 40mm black sphere |                                |
|                         | Relative humidity | Internal sensor                      | 0.03% ±2.5% RH [10% to 90%]            |
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The questionnaire included information on the social demographic backgrounds such as gender, height, weight, age, and current health conditions. Thermal comfort questions based on the individual perceptions of current indoor thermal conditions were also included in the questionnaire. The ASHRAE seven-point scale was used for thermal sensation vote (TSV) [14]. Based on the TSV, respondents’ thermal preference (TP) was assessed as expressed in the Nicol five-point scale [15, 16]. Table 2 shows the scale of TSV and TP.

Table 2: Scale of thermal sensation vote and thermal preference

| Scale | Thermal sensation vote, TSV | Thermal preference, TP |
|-------|---------------------------|------------------------|
| -3    | Cold                      | Much warmer            |
| -2    | Cool                      | A bit warmer           |
| -1    | Slightly cool             | No change              |
| 0     | Neutral                   | A bit cooler           |
| 1     | Slightly warm             | Much cooler            |
| 2     | Warm                      |                        |
| 3     | Hot                       |                        |

3. Results and Discussions
3.1. Thermal environment of experimental period
The uniformity of indoor operative temperature for each set point temperature was analysed by the measured parameters recorded by the sensors installed. Based on the findings, several thermal indices were used in this study to indicate the relation of one thermal index with another. The mean values of the four thermal indices obtained ($T_a$, $T_g$, $T_{op}$ and $T_{mrt}$) had significant linear regressions ($\rho < 0.001$) with strong correlations as shown in Table 2. These results indicate that any one of these thermal indices is appropriate to be used for further analysis. In this case study, the $T_{op}$ value has been used to determine comfort ranges in international standards (i.e. ASHRAE [14], CEN [17]).

Table 2: Regression equations and correlation coefficients of $T_a$ and other thermal indices

| Buildings | Items | $T_a \cdot T_g$ | $T_a \cdot T_{mrt}$ | $T_a \cdot T_{op}$ |
|-----------|-------|-----------------|--------------------|-------------------|
| U1 (N = 43) | Eq. r | $T_g = 2.3 + 0.92T_a$ | $T_{mrt} = 5.41 + 0.82T_a$ | $T_{op} = 2.15 + 0.93T_a$ |
| U2 (N = 20) | Eq. r | $T_g = 1.39 + 0.95T_a$ | $T_{mrt} = 3.79 + 0.85T_a$ | $T_{op} = 1.55 + 0.94T_a$ |

Note: U1: Universiti Teknologi Malaysia, Kuala Lumpur, U2: Universiti Malaysia Pahang, Pekan, N: Number of respondents $T_a$: Air temperature, $T_g$: Globe temperature, $T_{mrt}$: Mean radiant temperature, $T_{op}$: Operative temperature, r: Correlation coefficient; Note: all correlation coefficients are significant ($p < 0.001$).
3.2. Indoor operative temperature

Figure 3 shows the difference of mean $T_{op}$ at every seating location of the respondents. These results were obtained from the field study conducted on each group of the respondents who underwent the experiment in different days. With relevance to the indoor thermal environment, the mean values of $T_{op}$ obtained were slightly more or less for both U1 and U2 due to the outdoor temperature, $T_{od}$ between Kuala Lumpur and Pahang. Therefore, the measured indoor $T_{op}$ may be influenced by the outdoor environmental conditions. Based on the findings at U1, with regard to the set point temperatures of 16°C, 20°C, 24°C, and 28°C, the lowest mean indoor $T_{op}$ were measured at the seating location ‘G’, i.e. 17.8°C, 19.9°C, 23.1°C and 25.4°C, respectively. On the other hand, corresponding to the four aforementioned set point temperatures, the highest mean values of $T_{op}$ were obtained at the seating location ‘H’, i.e. 19.9°C, 20.5°C, 23.8°C, and 27.4°C, respectively. The other seating locations show almost uniform readings of the mean $T_{op}$.

However, the inconsistent mean values of $T_{op}$ for the two lowest set point temperatures at U2 i.e. 16°C and 20°C were 17.4°C and 19.8°C at the seating locations ‘A’ and ‘C’, respectively. The highest mean values of the $T_{op}$ obtained were 20.5°C and 22.5°C at seating locations ‘E’ and ‘G’, respectively. Nevertheless, for the set point temperatures of 24°C and 28°C, the obtained mean values of the $T_{op}$ were almost uniformly distributed with the difference of less than 1°C at all seating locations of the respondents. The lowest mean $T_{op}$ at the set point temperature of 24°C was 23.5°C at ‘G’, while the highest mean $T_{op}$ was 24.2°C at ‘E’. At the set point temperature of 28°C, the lowest mean $T_{op}$ was 26.2°C at seating locations ‘F’ and ‘G’, while the highest mean $T_{op}$ obtained was 27.5°C at seating locations ‘E’ and ‘G’. The differences of data measured were obtained from the mean of the overall results based on the number of data/occupants of a particular seating location and days of the experiment. Thus, the air temperatures of different locations in the living room can vary substantially.

![Figure 3](image_url)  
Figure 3: Mean $T_{op}$ of each seating location at the set point temperatures of 16°C, 20°C, 24°C, and 28°C at (a) U1 and (b) U2.

Based on the findings at U1, the highest mean $T_{op}$ for the set point temperature of 16°C was 20.4°C at seating location ‘I’; this indicates a difference of 4.4°C. At the set point temperature of 20°C, the highest mean reading was 21.7°C at seating location ‘D’, resulting in the difference of 1.7°C higher than the thermostat setting. Nonetheless, the difference for the set point temperature of 24°C was slightly lower i.e. about 0.2°C based on the reading of 23.8°C at seating locations ‘D’ and ‘G’. Meanwhile, the correlated highest mean temperature at the set point temperature of 28°C was 26.9°C, resulting in the difference of 1.1°C, at seating locations ‘D’ and ‘E’.

Regarding the results obtained from U2, the highest individual mean $T_{op}$ was obtained at ‘E’ with 20.5°C at the set point temperature of 16°C. The difference between the measured temperature and the
set point temperature was 4.5°C. At the set point temperature of 20°C, the highest mean $T_{op}$ obtained was 21.7°C at seating location ‘I’. This results in the difference between the set point and the measured temperatures to be 1.7°C. As for the set point temperature of 24°C, the measured temperature was 24.5°C at seating locations ‘D’ and ‘E’, with the temperature difference of only 0.5°C. Meanwhile, the highest mean $T_{op}$ measured was 26.9°C for the set point temperature of 28°C, resulted in the difference of 1.1°C at seating location ‘E’. Table 5 shows the summary of the temperature difference for each set point temperature and the highest mean value of $T_{op}$ obtained from the seating locations of the respondents at U1 and U2.

| Description | U1 | U2 |
|-------------|----|----|
| Set point temperature, ($T_s$) | 16°C | 20°C | 24°C | 28°C | 16°C | 20°C | 24°C | 28°C |
| Mean $T_{op}$ (°C) | 20.4 | 21.7 | 23.8 | 26.9 | 20.5 | 21.7 | 24.5 | 26.9 |
| $\Delta t$ (°C) | 4.4 | 1.7 | -0.2 | -1.1 | 4.5 | 1.7 | 0.5 | -1.1 |
| Seating location | I | D | D, G | D, E | E | I | D, E | E |

Note: $T_{op}$: Operative temperature, $\Delta t$: Difference of temperature ($T_{op} - T_s$)

3.3. Thermal sensation and preference vote

This section presents an analysis of individual thermal sensation vote (TSV) and thermal preference (TP) based on seating location. Convective heat transfer to the skin varies with surface temperature and local air velocity. TSV is closely related to the comfort of an individual since the human skin is highly sensitive to thermal sensation [18]. People with differing thermal histories may respond differently [1, 19]. Therefore, occupants of a room may feel the increase or decrease in the indoor comfort temperature with the presence of air velocity [20]. The increased air velocity may reduce skin moisture. The results of the individual TSV and TP were obtained from the questionnaire survey that was based on the ASHRAE seven-scale votes and filled out by the respondents after the experiment was performed. The respondents were advised to remain seated at the same seating position until the completion of the survey session.

For both U1 and U2 cases, at the set point temperature of 16°C, the vote obtained for most respondents at seating location ‘A’ was ‘-3 cold’ with the mean value of TSV between -2.3 and -2.6. About 38% of the respondents voted for ‘-3 very cold’ for TSV, while about 71% voted ‘-1 a bit warmer’ for TP. Nevertheless, most respondents at seating locations ‘B’, ‘C’, ‘D’, and ‘E’ voted ‘-3 cold’ for TSV ‘-1 a bit warmer’ for TP. In addition, 62% voted ‘-2 cool’ for TSV and ‘-1 a bit warmer’ for TP at the set point temperature of 20°C. The mean value of TSV at U1 and U2 was between -1.7 and -2.5, suggesting that the respondents literally felt ‘-2 cool’ and ‘-3 cold’, respectively at their current seating locations.

Meanwhile, at the set point temperature of 24°C, 41% of the respondents voted ‘0 neutral’ for TSV while 54% of them preferred ‘0 no change’ for TP. The highest percentage of TP obtained revealed that most respondents felt almost neutral at most of the seating locations in both experimental rooms. Relatively, 38% voted ‘1 warm’ for TSV with the mean value between 0.53 and 1.5 which lies in the categories of ‘neutral’, ‘slightly warm’, and ‘warm’ on the TSV scale. The mean value of TP was between 0.6 and 1.8 with the preferences of ‘a bit cooler’ to ‘much cooler’, respectively, at most of the seating locations in the experimental rooms. It could be the natural desire of most people living in a hot climate to prefer a cooler condition, although they probably accepted the prevailing conditions [21]. The strong correlation ($R^2 > 0.8$) between the mean value of TSV and TP has been found, as shown in Figure 4.
Figure 4: Correlation of thermal preference votes in relation to thermal sensation votes for the set point temperatures of 16°C, 20°C, 24°C, and 28°C

3.4. Comfort temperature according to the Griffiths’ method

The Griffiths’ method was considered to calculate the comfort temperatures of the respondents individually, based on TSV when the regression analysis was unreliable. The applicable value of the regression coefficient for the day-survey was 0.5/K [22]. Hence, a 2K change in the operative temperature is associated with a change of one unit scale in the average thermal sensation based on the ASHRAE seven-point scale [23]. This is to obtain the temperature that might result in neutrality as discussed in previous studies [5, 24-26] that were conducted in hot and humid conditions in Malaysia and Japan. Therefore, the output of the Griffiths’ method is comfort temperature that can be calculated from each TSV and the indoor operative temperature, $T_{cop}$. The mean temperature is calculated based on the following equation (1) [22]:

$$T_c = T + \frac{(0 - TSV)}{\alpha}$$

From the equation, $T_c$ indicates the comfort temperature (°C), $T$ refers to temperature (°C), 0 indicates a neutral condition, and $\alpha$ is the Griffiths’ constant or regression coefficient.

In estimating the Griffiths’ comfort temperatures, the constant values of $\alpha$, 0.25, 0.33 and 0.50 were used as shown in Table 5 based on each set point temperature, $T_s$. In this study, the constant coefficient of 0.50 was used as the Griffiths’ constant for estimating the comfort temperature in the previous studies [5, 24-26] of hot and humid conditions in Malaysia and Japan. The mean $T_{cop}$ and its standard deviations were calculated by using the $T_{op}$ data. The mean values obtained for the set point temperatures of 16°C, 20°C, 24°C, and 28°C from U1 were 24.2°C, 24.9°C, 25.4°C, and 25.6°C, respectively. The standard deviations of the mean $T_{cop}$ were 1.7°C, 1.2°C, 1.8°C, and 2.2°C respectively. Meanwhile, at U2, the mean values of the $T_{cop}$ obtained at the same aforementioned set point temperatures were 22.7°C, 25.4°C, 24.9°C, and 24.6°C, respectively. The standard deviations obtained for the mean $T_{cop}$ were 1.6°C, 1.3°C, 1.7°C and 1.5°C, respectively.

Table 5: Descriptive statistics for the comfort temperatures calculated by the Griffiths’ method

| $\alpha$ | Comfort temperature, $T_{cop}$ |
|----------|-------------------------------|
|          | U1 (N = 43)                    | U2 (N = 20)                    |
|          | $T_s$ | 16°C | 20°C | 24°C | 28°C | $T_s$ | 16°C | 20°C | 24°C | 28°C |
| 0.25     |       |      |      |      |      |       |      |      |      |      |
|          | 28.7  | 28.6 | 27.3 | 24.7 |      | 26.7  | 29.7 | 26.1 | 22.6 |      |
|          | (2.9) | (2.4) | (3.6) | (4.4) |      | (3.0) | (2.3) | (3.1) | (2.9) |      |
| 0.33     |       |      |      |      |      |       |      |      |      |      |
|          | 26.5  | 26.8 | 26.4 | 25.1 |      | 24.8  | 27.6 | 25.5 | 23.6 |      |

Table 5 continues...
4. Conclusions

The field study and questionnaire survey were conducted simultaneously to investigate the respondents’ thermal preferences in the experimental living rooms located in UTM Kuala Lumpur (U1) and Universiti Malaysia Pahang, UMP (U2), using four set point temperatures. The conclusions of the current field study are as follows:

- For both U1 and U2, the mean values of TSV at the set point temperature of 24°C ranged between -0.5 to 0.99 with the TP between 0.3 to -0.6. By increasing and decreasing the set point temperature, the TP also change to either ‘prefer warmer’ or ‘prefer cooler’.

- Apparently, some of the respondents preferred the indoor condition to be ‘a bit cooler’ while voting ‘neutral’ or ‘cool’ for TSV. Hence, the findings are in accordance with findings of the field study conducted in Nepal [27]. This suggests that despite feeling satisfied with the current conditions, most of the respondents preferred a warmer or cooler environment due to their natural preferences and comfort levels.

- The range of the comfort temperatures calculated by using the Griffiths’ method was between 24.2°C and 25.6°C at U1 and between 22.7°C and 25.4°C at U2. The difference of the minimum comfort temperatures for both U1 and U2 was about 1.5°C, while the difference of the maximum comfort temperatures was slightly lower i.e. about 0.2°C.

It was observed that the respondents in warmer thermal conditions would prefer either ‘a bit cooler’ or ‘no change’, while those in colder thermal conditions would prefer either ‘a bit warmer’ or ‘no change’. The thermal environment is considered comfortable when the respondents reported a ‘neutral’ feeling in terms of their comfort level [11].

Acknowledgment

This work was supported by the Johnson Controls-Hitachi Air Conditioning [Vot 4B395], Ministry of Education (MOE) through the Fundamental Research Grant Scheme [FRGS/1/2019/TK07/UTM/02/5], and Universiti Teknologi Malaysia (UTM) under the Industrial-International Incentive Grant [Vot 01M89].

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