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Associating thermal comfort and preference in Malaysian universities' air-conditioned office rooms under various set-point temperatures

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ABSTRACT

Overcooling indoor spaces in hot-and-humid regions indicate excessive usage of air conditioner (AC). Understanding the occupants' thermal perception in AC settings helps navigate the cooling energy required. This study investigated thermal comfort in biased and non-biased environments and examined the occupants' preferences. Four set-point temperature conditions (Original, Original ±2 °C, and MS Standard) were implemented in a semi-controlled field study done in 19 offices. 628 samples were taken from 42 occupants via thermal measurements and questionnaire surveys. The indoor air temperature in the typical AC settings (Original set-point) was 23.1 °C, denoting non-compliance to the local guideline. The results showed that occupants generally felt more comfortable when the indoor air temperature was increased. The mean comfort temperature was 24.6 °C, and the proportion of comfort votes depletes when the operative temperature reaches 26 °C. The preferred temperature was estimated at 23.9 °C, and the linear relationship with comfort temperatures revealed that occupants preferred a cooler environment despite being thermally comfortable. The findings suggest that occupants could tolerate higher AC settings well, but thermal preference may be a critical factor in estimating the comfort temperature limits.

1. Introduction

World demand for commercial air conditioners (AC) in 2018 has a two percent increase from the previous year, reaching 14.9 million units [1]. AC demand and energy use will likely rise further in tropical regions, considering it is the fastest-growing region [2]. More than half of buildings' energy consumption in hot and humid tropical climates such as Singapore and Malaysia accounts for space cooling purposes [3,4]. Air-conditioning systems are typically equipped with temperature selections, allowing for customized indoor comfort and relief. A study conducted in the Philippines found a 0.5 to 8.5% increase in electricity demand with every one-degree Celsius temperature rise, equivalent to 21 (±10.4) watts per person [5]. A controlled set point could tremendously benefit energy consumption in shared spaces [6].

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In most cases, the regulation for ACs in buildings applies the steady-state predicted mean vote (*PMV*) model. The *PMV* model is based on Fanger's [7] heat-balance approach that considers the thermal comfort parameters (metabolic rate, clothing insulation, humidity, airspeed, air and mean radiant temperatures). Such cases are present in international standards from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE Standard 55:2017) [8], the International Standard ISO 17772–1:2019 [9], and the European Standard EN16798:2019 [10] (successor to the EN1525:2007 [11]). Discrepancies in the *PMV* model are pointed out in the Environmental Design Guide A of the Chartered Institution of Building Services Engineers (CIBSE) [12], suggesting that it often contradicts field studies. The CIBSE guideline provides an adaptive approach for buildings with heating and cooling systems on top of *PMV*-based temperature guidelines.

Although adaptive models, which are dependent on outdoor air temperature, are usually applicable to naturally-ventilated (NV) buildings, recent research has looked into integrating the adaptive approach in other ventilation modes. For example, Sánchez-García et al. [13,14] used set-point temperatures based on adaptive models in EN1525 and ASHRAE Standard 55 to predict energy-saving potential. The computational method of Adaptive-Comfort-Control-Implemented-Model (ACCIM) was applied to air-conditioned dwellings, where they found that adaptive set-point temperatures could potentially save 83% energy [15]. Upon the release of the ASHRAE Global Thermal Comfort Database II, Parkinson et al. [16] investigated the adaptive model's relevance and found thermal adaptation in air-conditioned, mixed-mode, and naturally-ventilated buildings. The collected data of thermal adaptation in NV and AC buildings in Asia are higher by 1 to 2 °C than those of their Western counterparts.

Many attempts to save energy often neglect human comfort [17]. The indoor environment is vital for comfort and work performance in offices [18,19]. Thermal comfort significantly affects indoor environment satisfaction more than visual, acoustic, and air quality [20]. A comfortable thermal environment in the workplace can have economic benefits as health and productivity are enhanced [21]. On the other hand, thermal discomfort leads to negative attitudes among office occupants and reduced enthusiasm for work activities [22]. One thermal condition may not satisfy all occupants in a common shared space due to individual preferences. Based on Fanger's [7] studies, a minimum of 5% dissatisfaction is expected even when the highest comfort level is achieved ($PMV = 0$). Thus, 80% of the majority votes is the threshold for an acceptable thermal environment, according to ASHRAE [8].

1.1. *Thermal comfort studies in tropical and subtropical climates*

Field studies in air-conditioned office buildings have shown some patterns of overcooling, causing significant discomfort among occupants. A recent study by Fukawa et al. [23] addressed the overcooling problem in Thailand, Indonesia, and Singapore. They proposed setting the indoor temperature higher than 24.5 °C would increase comfort for occupants with lighter clothing (0.30–0.59 *clo*). Mustapa et al. [24] studied the thermal comfort of 28 participants in a university office in Kuala Lumpur using three different AC settings, 20 °C, 24 °C, and 28 °C. The mean comfort temperature in each AC setting was 25.3 °C–26.2 °C. However, the AC settings did not accurately reflect the indoor air temperature, especially at 20 °C, where the measured mean value was approximately 4.6 °C higher. As a result, over 80% of thermal sensation votes fall in the same category. de Vecchi et al. [25] investigated thermal comfort in centralized AC buildings constantly operating at 24 ± 2 °C, and performed comparison with mixed-mode (MM) buildings with AC and operable windows. The authors discovered that the AC was always turned on in MM buildings regardless of the season. The study debunked the assumption that a static thermal environment offers higher comfort levels by revealing that MM buildings with occupant control recorded slightly higher comfort levels than the centralized AC mode.

A field study in 2015 investigated thermal comfort in the hot and humid climate (Malaysia, Indonesia, and Singapore) and hot summer in Japan [26]. The thermal comfort zone in Malaysia was estimated between 24 °C and 30 °C using probit regression with an optimum value of 27 °C. In Indonesia, the average comfort temperature in AC or cooling mode obtained via Griffiths' method was 26.3 °C, identical to the result in Singapore with the same ventilation mode, which was 26.4 °C. The results in Malaysia and Japan, found to be comparable, were slightly higher at 25.6 °C and 25.8 °C, respectively. Between 2017 and 2019, a field study in AC offices was conducted by Sikram et al. [27] in Singapore and Thailand to study human comfort and building-related symptoms. Comfort complaints and building-related symptoms like fatigue and drowsiness occur when the temperature is lower than 24 °C. The study concluded that the lower the room temperature, the greater the risk of building-related symptoms.

In 2016, a field study by Wu et al. [17] projected that 8.6% of cooling energy could be saved in summer if the buildings followed the Chinese architecture standard. Compared to the *PMV* model, the ASHRAE adaptive comfort model was more applicable in split AC buildings with an upper limit of 29.4 °C and 80% acceptability. The applicability of the *PMV* model was also investigated by Zhao et al. [28] to assess the energy efficiency in an AC office building in Qatar. The *PMV* model underestimated comfort level when occupants felt slightly warm and overestimated when actual votes were slightly cold. Wu et al. [29] performed a study to investigate thermal adaptation in AC buildings. Most indoor temperature and humidity data were outside the *PMV/PPD*-based ASHRAE comfort zone in summer. However, compared with the ASHRAE's adaptive comfort, the summer data were mainly acceptable at a 90% rate with an upper limit of 30.4 °C, proving that the locals can adapt to a warm environment. Likewise, a climate chamber study in a hot and humid region in China by Yang et al. [30] revealed an overestimated *PMV* model and warmer thermal adaptation among respondents due to habituation.

Indraganti and Boussa [31] conducted a year-long study on adaptive thermal comfort and thermal feelings in ten office buildings in Doha, Qatar. The mean Griffiths' comfort temperature was 24.0 °C, and the adaptive relationship of indoor comfort temperature varied by about ½ K for a 10 K change in outdoor temperature. Due to the low air movement measured in the investigated offices, the authors suggested that increasing airspeeds could increase the indoor temperature for energy saving. Another study in two hot and humid regions in India by Indraganti et al. [32] revealed that in the AC mode, the comfort temperature via Griffiths' method was 26.4 °C, and the adaptive model obtained a similar relationship with the CIBSE guide. Lopez-Perez et al. [33] performed a field study on 27 educational buildings in 2017. The indoor mean air temperature in AC buildings was 23.8 °C, and the comfort temperature via

Griffiths' method was 24.7 °C. According to the adaptive model formed in the AC mode, the lower and upper limits were predicted to be 25.2 °C and 27.1 °C, respectively. Based on these findings, the authors suggested that a 1 °C increase in indoor temperature would improve comfort and save energy.

1.2. Malaysian indoor environment standard

In Malaysia, buildings with mechanical cooling systems adopted the 2014 Malaysian Standard (MS) 1525 code of practice, referencing the ASHRAE Handbook [34,35]. In promoting energy efficiency in non-residential buildings, the minimum operative temperature is recommended at 24 °C. However, there is no explicit remark that the guideline integrates local thermal comfort studies, which may lead to misrepresentation of indoor comfort, considering the cultural habit and adaption to climate conditions influences comfort expectations. Aliagha and Cin [36] surveyed the local perceptions on proposed Malaysian Cool Biz energy conservation elements adapted from the Japanese Cool Biz campaign. The 5-scale Likert survey on 200 participants revealed a mean score of 3.4 on maintaining office temperature at 24 °C to conserve energy. Although more than half of the participants concurred that the Cool Biz campaign is a good concept adopted in Malaysia, 62% agreed that the implementation would create an uncomfortable workplace. There was an apparent underestimation of the minimum Malaysian guideline from a field study on 130 respondents in Malaysian university buildings where the comfort temperature was calculated at 25.6 °C [26].

1.3. Comfort and preferred temperatures

Generally, comfort temperature can be referred to as neutral temperature as it mainly takes into account the neutral thermal sensation vote (*TSV*), following the Fanger's Predicted Mean Vote (*PMV*) model [7]. Arguably, neutral votes alone may not accurately depict occupants' comfort [37,38] as it neglects occupants' preferences to be in a non-neutral environment. An individual's inclination to be outside the existing thermal environment might indicate that thermal comfort is not satiated. Recent studies by Shahzad et al. [39,40] questioned the applicability of neutral temperature in measuring thermal comfort and found that 36% of occupants did not want to be in a neutral thermal environment, and thermal comfort conditions were not consistent throughout the day. Shahzad and Rijal [41] later recommended applying the preferred temperature in place of the neutral temperature when investigating the range of the comfort temperature after discovering a significant relationship between the preferred and neutral temperatures. The study conducted in Japan, Norway, and the United Kingdom reported that occupants preferred a cooler environment when the neutral temperature was 26 °C and a warmer environment when thermal neutrality was 22 °C. Hwang et al. [42] conducted a study at workplaces in tropical Taiwan where the preferred temperature was 2 °C lower than the neutral temperature (25.8 °C). It is common for hot and humid climate zones to have lower temperature preferences. Similarly, a study by Wu et al. [17] conducted in a subtropical climate in several office buildings in Changsha, China estimated a preferred temperature of 26.0 °C when the neutral temperature was 26.9 °C. On the contrary, a Brazilian study observed a higher preferred temperature (25.8 °C) when the neutral temperature was 23.3 °C.

1.4. Research aims

Field studies in air-conditioned buildings provide valuable information on thermal comfort and adaptive behaviour, but measuring in occupant-controlled environments may leave the possibility for partial responses [26,32,43,44]. Semi-controlled field experiments comparing occupants' sensations to measured thermal settings could aid in better understanding the comfort range of occupants in air-conditioned buildings.

Studies have pointed out the slight dissatisfaction among occupants in a thermally neutral state. In general, a lower temperature is preferred in hotter climates, but when the indoor temperature is less than 24 °C, a warmer temperature is preferred [23]. Shahzad and Rijal [41] explored the relationship between preferred and neutral temperatures in seasonal climates, and few data are available in tropical climates.

This research explores thermal comfort in Malaysian university office buildings at four different set-point temperatures (Original, Original − 2 °C, Original + 2 °C, and MS Standard). The objective is to estimate comfort temperature and investigate thermal sensation and acceptability in each set point. The results are compared with local [34] and international [8–10,12] standards to examine the compatibility. Thermal preference is used to evaluate the preferred temperature, and the association with thermal comfort is identified.

2. Methodology

2.1. Geographical and climate description of study location

The field study took place in urban cities, Kuala Lumpur and Shah Alam, located in Klang Valley, occasionally referred to as Greater Kuala Lumpur. Geographically, the Titiwangsa Mountains forge the valley to the north-east, and the primary Klang River flows through the Straits of Malacca to the west. Malaysia is labeled as the tropical climate group Af from the Köppen climate categorization as it is within 15° latitude of the equator [45]. The investigated buildings in this study reside in the Af region located at 3° north of the equator (3°N, 101°E). The average precipitation or rainfall of countries in the Af category is 60 mm, and the climate is ordinarily hot, very humid, and wet all year long.

Malaysia receives an average sunshine duration of approximately 6 h a day with no seasonal weather; hence the average air temperature is relatively constant. Air temperature in West Malaysia is higher on average than in East Malaysia. The distance between Kuala Lumpur and Shah Alam is roughly 20 km. Fig. 1 shows the annual outdoor air temperature and outdoor relative humidity in both cities. The data are relatively constant throughout the year. The outdoor air temperature difference between the two cities is less than

1 °C, while relative humidity variation in both locations did not deviate more than 5%. Klang Valley in the west usually experiences the highest number of rainfalls in October and November, which explains the air temperature dip and the slightly higher relative humidity in both months. The average outdoor air temperature and relative humidity during the measurement period in Kuala Lumpur and Shah Alam are 27.9 °C and 81.5%, respectively.

2.2. Subjects' information

The demographic information collected in this study was age and gender. 25 female (59.5%) and 17 male (40.5%) respondents comprised of university staff and students that participated in this study. The age ranges from 20 to 49 years old, with an average age of 31 years old for both male and female respondents. The mean height and weight were 1.65 m and 64.8 kg, respectively. The Body Mass Index (BMI) was 23.8 on average and within the normal range (18.5–25.9); however, some respondents were underweight or overweight. The body weight, height, and BMI of male respondents were higher than females and comparable to the average size of men and women in Malaysia [46]. On average, clothing insulation among females was higher with 0.61 *clo* while among males was 0.53 *clo*. This was possibly due to headscarves worn by most Muslim female respondents. The metabolic rates were mainly sedentary, with an average of 1.1 met, since the main activities involved were reading, writing, typing, or seated quietly.

2.3. Investigated buildings

The field study was conducted at public institutions, Universiti Teknologi Malaysia in Kuala Lumpur (UTMKL) and Universiti Teknologi MARA in Shah Alam (UiTM). The universities are built around the densely populated urban zones. As this research explores thermal comfort under varying temperature conditions, the criteria considered in building selection were non-residential office buildings that are mechanically ventilated with interchangeable AC settings. During investigations, occupants were not notified of any AC setting adjustments. Table 1 shows the overview of investigated buildings in both locations, and the building façade is shown in Fig. 2.

This study measures the thermal environment in private offices with single occupants and shared offices with multiple working cubicles. The thermal environment was measured in one workspace at a time to obtain specific data for each occupant. During the measurement process, the investigated offices were frequently entered to observe indoor air temperature stability in the rooms and change AC settings according to each set-point condition. The windows were closed to avoid significant temperature fluctuation when the AC was turned on in the office spaces. However, there was no strict requirement on closing the office doors to allow office occupants to work without interruptions, but occupants were advised to close the doors after opening them. It was challenging to guarantee the availability of occupants during the measurement. Hence, appointments were set up with office administrators and occupants to avoid work interruptions and scheduling conflicts.

2.4. Thermal measurement

The field measurement combined quantitative and qualitative data collection. The indoor thermal parameters measured were air temperature (T_a), globe temperature (T_g), relative humidity (RH), and air velocity (v_a) simultaneously while gathering subjective responses from questionnaires. Table 2 shows the specification of instruments that contains the range and accuracy of the devices. Meanwhile, the operative temperature (T_{op}) and mean radiant temperature (T_{mrt}) were estimated according to the equations from the ASHRAE Handbook [35] as defined in Eq. (1) and Eq. (2).

$$T_{op} = AT_a + (1 - A)T_{mrt} \tag{1}$$

$$T_{mrt} = \left[\left(T_g + 273\right)^4 + \frac{1.1 \times 10^8 V_a^{0.6}}{\varepsilon D^{0.4}}\left(T_g - T_a\right)\right]^{1/4} - 273 \tag{2}$$

In Eq. (1), A is a constant with a value of 0.5 when V_a is less 0.2 m/s, 0.6 when V_a is 0.2 to 0.6 m/s, and 0.7 when V_a is 0.6 to 1.0 m/s. In Eq. (2), ε refers to the emissivity of the globe, and D is the diameter of the globe. The value of ε used in this study is 0.95 for the black globe, while D is 0.04 m.

Outdoor air temperature and relative humidity in Kuala Lumpur were recorded via a weather station located on the rooftop of the

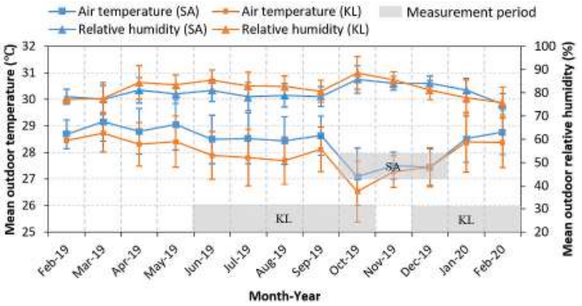


Fig. 1. Annual mean outdoor air temperature and relative humidity in studied locations. Error bars indicate the standard deviation.

Table 1
Information on investigated buildings.

City	Coordinate	Building code	Floor area (m^2)	Total floor	Investigated floor	Orientation	Glazing ratio	Shading device	Flooring finish	Subject	N
Kuala Lumpur	3°10′N, 101°43′E	KL1	4272	10	4	E	0.19	-	Wool carpet	2	32
					5	E	0.59	Vertical blinds	Wool carpet	3	48
					10	W	0.79	Vertical blinds	Tiles	7	94
		KL2	542	2	2	S-W	0.18	Vertical blinds	Wool carpet	8	120
		KL3	1244	16	8	S-W	0.81	Translucent roller blinds	Wool carpet	9	144
					13	N-W	0.90	Translucent roller blinds	Wool carpet	2	29
Shah Alam	3°4′N, 101°30′E	SA1	771	1	1	N-E	0.30	Vertical and roller blinds	Tiles	7	133
		SA2	563	3	2	N-W	0.63	Translucent roller blinds	Tiles	2	28
									Total	42	628

Note: N: North, E: East, W: West, S: South, *N*: Number of data collected.

Fig. 2. Investigated buildings in this study a) KL1, b) KL2, c) KL3, d) SA1, and e) SA2.

Table 2
Specifications of instruments used in field measurement.

Device	Sensor	Parameter measured	Range	Accuracy
T&D TR-77Ui	HHA-3151	Air temperature	− 30 to 80 °C	±0.3 °C (10 to 40 °C) ± 0.5 °C (Other temperatures)
		Relative humidity	0 to 99% RH	±2.5% RH (at 25 °C and 10 to 85% RH) ± 4% RH (at 25 °C and 0 to 10% RH or 85 to 99% RH)
HOBO Data Logger	Internal sensor	Relative humidity	5 to 95% RH	±2.5% (10 to 90% RH)
	TMC1-HD	Air temperature	−40 to 100 °C	±0.25 °C (0 to 50 °C)
	TMC1-HD + 40 mm black sphere	Globe temperature	−40 to 100 °C	±0.25 °C (0 to 50 °C)
Kanomax 6501-0G	Needle Probe 6542-2G	Air Velocity	0.01 to 50 m/s	±2% or 0.015 m/s

investigated building KL1. It is approximately 68 m above ground and within a 1-km radius from KL2 and KL3. Components of the weather station from Campbell Scientific are listed in Table 3 and Fig. 3. The same weather station was used to study microclimate and wind characteristics in Kuala Lumpur [47,48]. The outdoor parameters in Shah Alam were downloaded from the *Wunderground* website [49] with 1-h sampling intervals based on the weather station set up in Subang International Airport, approximately 9 km from the investigated buildings in Shah Alam.

2.5. Experimental setup

During the field measurement, the instruments for measuring indoor environment parameters i.e. T_a, T_g, RH, and V_a were configured on a retort stand and set at a 10-s interval, as shown in Fig. 3. The instruments were placed at a height between 1.0 and 1.2 m above the floor following the guide from Standard 55 [8]. Two TMC1-HD sensors were connected to the HOBO data logger; one was

Table 3
List of components used in the Kuala Lumpur weather station.

Weather station component	Model
Cup anemometer	Wind Sentry Anemometer
Rainfall gauge	RIMCO8000
Temperature and relative humidity probe (with solar radiation shield for protection from direct sunlight)	CSL Temp/RH Probe SDI
Pyranometer	Apogee Silicon
Data logger	CR-1000

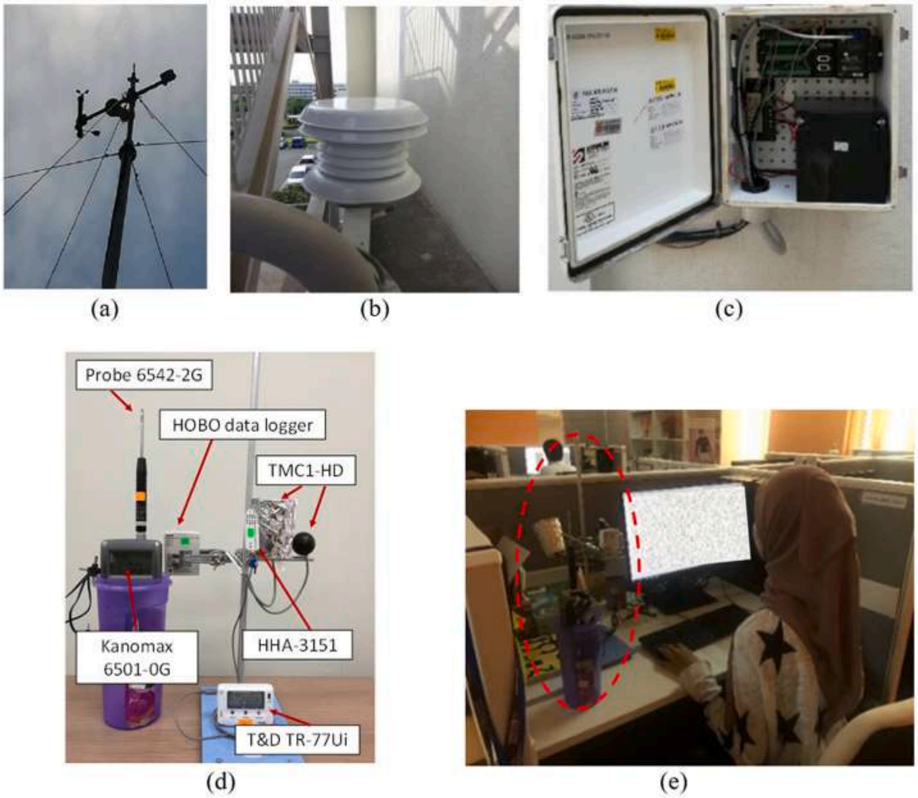


Fig. 3. Photos of the weather station on the rooftop of KL1; a) Cup anemometer, rainfall gauge, and pyranometer setup, b) Temperature and relative humidity probe covered in a solar radiation shield, c) Datalogger. Photos of (d) instruments setup and (e) field measurement setup. The red dotted circle indicates the instrument setup in the respondents' workspace. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

encased in aluminum foil to measure indoor air temperature and the other was topped with a black painted 40-mm sphere (ping pong ball) to measure the indoor globe temperature. The aluminum foil was used to reflect radiant heat from either sun or surrounding surfaces due to its low emissivity (0.04) and low thermal mass which prevents heat storage [50], allowing the sensor probe to measure a more accurate reading of air temperature. On the other hand, the high-emitting black sphere (0.95) was utilized to absorb radiant heat estimated from cold to hot environments [51]. The equipment setup is shown in Fig. 3(e). As the indoor thermal measurements were taken individually in all studied locations, the set-point temperature differs for each respondent in shared spaces.

2.6. *Set-point temperature conditions*

Four set-point temperature conditions (Original, Original ±2 °C, and MS Standard) were established to explore occupants' perceptions from low to high set points (see Table 4). The Original set point refers to the pre-existing indoor thermal condition in the office rooms that occupants typically experience. Hence, there was no intervention during the field measurement, and the AC settings were pre-determined by occupants. The Original ±2 °C set point was formed to extend the occupants' ordinary temperature set-points and investigate a significant comfort level in reducing and elevating the indoor air temperature. By referring to the upper and lower limit differences in Standard 55, the two-degree Celsius difference was set up (Original ± 2 °C) to differentiate from the Original set point [8]. Wang et al. [52] adopted a similar approach in a climate chamber study in China, but they designed five indoor air temperature set-points with fixed values. In this study, each set point had up to 1^{o}Celsius of fluctuation, considering the thermal parameters were measured in real office settings where external factors such as surface radiant heat could temper the indoor temperature. For the MS Standard set point, the indoor air temperature was maintained roughly at 24 °C following the minimum recommendation of Malaysian Standard MS1525.

Table 4
Description of each set-point temperature condition.

Set-point	Description
Original	Typical day-to-day ambient temperature for each respondent
Original −2 °C	Reduced ambient temperature by 2 (±1)°C from the Original set-point
Original +2 °C	Elevated ambient temperature by 2 (±1)°C from the Original set-point
MS standard	Ambient temperature following the minimum temperature guideline of Malaysian Standard MS1525:2017 at 24 (±1)°C

2.7. Data collection method

This study requested occupants to provide personal information and participate in the field measurement more than once. Thus, occupants were briefed on the experimental procedure and asked to sign a written consent following the Personal Data Protection Act 2010. Before conducting the field study, the information on physical characteristics or the anthropometry data of occupants was collected. The thermal measurements (quantitative) and survey (qualitative) data were simultaneously conducted. The indoor thermal parameters were measured using the instruments listed in Table 2 and the experimental setup in Fig. 3, while the subjective responses were obtained via a questionnaire survey. Data were collected in two sessions: morning between 8:00 to 11:00 and afternoon between 14:00 to 18:00.

A longitudinal approach was used by repeating the measurement of every set-point temperature condition at least twice per session. A similar method was applied in previous thermal comfort field studies [26,53]. Although there were no effects between morning and afternoon sessions against thermal sensation votes (TSV), the sessions closely matched the occupants' daily hours in the office. As shown in Fig. 4, the field measurement process began with the Original set point, followed by the Original ±2 °C set point, and the MS Standard set point in random order. The indoor air temperature was controlled by setting the AC thermostat available in each investigated office. The various set-point temperature settings were explained to the occupants so they were able to understand and recognize the overall context and significance of the study. However, the field measurements were executed strictly without occupants' acknowledgment, on which a set point was used to avoid biased responses. The AC setting displays were covered during the field measurement as an added measure. The indoor air temperature was recorded for 60 to 70 min and monitored at every 15-min mark to confirm the fluctuations (±1 °C). Later, the respondents answered the questionnaire survey in five to 10 min. The quantitative data collected for analysis were the average value of 10- to 20-min measurement with 10-s intervals before the survey was answered. All measured indoor data were saved and downloaded after each measurement session to ensure no data was faulty or lost.

2.8. Thermal comfort survey

The questionnaire used in the thermal comfort survey was prepared using Google Form, along with Malay translation. The contents were based on previous studies on thermal comfort in non-residential buildings [26,54,55]. The questionnaire was split into two parts, Part A and Part B. Since socio-demographics are the only characteristics of the sample population, the information in Part A (age, gender, height, and weight) was obtained once at the beginning of the field study, right after respondents signed the written consent. Part B of the questionnaire was repeatedly distributed to respondents via emails and *Whatsapp* messages at the designated time.

Part B of the questionnaire was disseminated to respondents during each measurement session to acquire the *right-here-right-now* responses. The questionnaire includes room occupancy, health condition, subjective responses, adaptive actions, and clothing insulation. The following subjective parameters were quantified on multi-point scales (see Table 5); thermal sensation vote (TSV), thermal preference (*TP*), thermal acceptability (*TA*), humidity preference (*HP*), air movement vote (*AMV*), air movement acceptance (*AMA*), and overall comfort (*OC*). The seven-point *TSV* scale was adopted from the Society of Heating, Air-conditioning, and Sanitary Engineering of Japan (SHASE), considering the words such as "warm", "hot", "cold", and "cool" in ASHRAE's *TSV* have similar meanings in the Malay language. A similar approach was taken in a previous thermal comfort study in Kuala Lumpur to avoid misinterpretation [55]; the SHASE's *TSV* was used in this study alongside other quantified parameters. The unhealthy responses were omitted to avoid skewed results; measurements were repeated with the subjects once they had gained their health; this was done to achieve a consistent number of responses per subject. Their activity levels and clothing items were asked during the last 15 min, and the results corresponded with the metabolic rates and the *clo* values listed in ASHRAE's Standard 55. Additionally, the survey recorded adaptive actions of respondents towards their thermal surroundings, such as drinking water, rolling up sleeves, adding a layer of clothing, and moving around.

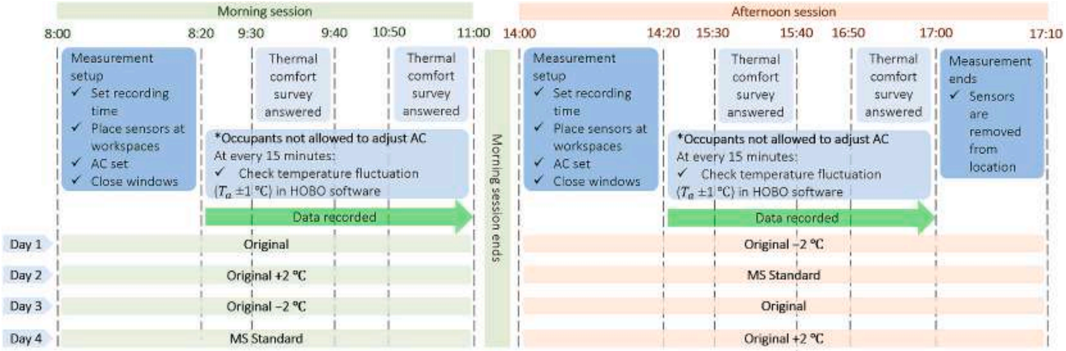


Fig. 4. Field study timeline.

Table 5
Subjective evaluation scale survey used in this study.

Scale	Thermal sensation vote (*TSV*)	Thermal preference (*TP*)	Thermal acceptance (*TA*)	Humidity sensation (*HS*)	Humidity preference (*HP*)	Air movement vote (*AMV*)	Air movement acceptance (*AMA*)	Overall comfort (*OC*)
−3	Very cold	-	-	Very dry	-	-	-	-
−2	Cold	Much warmer	-	Dry	Much humid	-	-	-
−1	Slightly cold	A bit warmer	-	Slightly dry	A bit humid	-	-	-
0	Neutral	No change	Not acceptable	Neutral	No change	No movement	Not acceptable	-
1	Slightly hot	A bit cooler	Acceptable	Slightly humid	A bit drier	Low	Acceptable	Very uncomfortable
2	Hot	Much cooler	-	Humid	Much drier	Neither high nor low	-	Moderately comfortable
3	Very hot	-	-	Very humid	-	High	-	Slightly uncomfortable
4	-	-	-	-	-	-	-	Slightly comfortable
5	-	-	-	-	-	-	-	Moderately comfortable
6	-	-	-	-	-	-	-	Very comfortable

3. Results and discussion

3.1. Indoor thermal data

In this study, the environmental parameters of thermal comfort were obtained in two ways; direct measurement and estimation. The following sections will discuss the indoor thermal environment results based on the four set-point conditions, namely, Original, Original ±2 °C, and MS Standard. Table 6 summarizes the measured parameters (indoor air temperature, globe temperature, relative humidity, and air velocity) and the estimated parameters (indoor mean radiant temperature, operative temperature, and absolute humidity). Indoor air temperature in the Original set-point was mainly lower than the minimum recommendation of the local standard of 24 °C. Generally, the globe temperature is slightly higher than the air temperature in each location and all set-point conditions. In contrast, the mean radiant and operative temperatures were almost identical to the globe temperature.

The maximum mean relative humidity value in each studied location was mainly recorded in the Original +2 °C set point. The estimated absolute humidity shows a minimum mean when air temperatures were reduced in the Original −2 °C set point and a maximum mean in the Original +2 °C set point for every location. The mean indoor air velocity ranges between 0.14 and 0.25 m/s, and most areas recorded an average air velocity of around 0.20 m/s. With multiple thermal indices used in this study, it is imperative to assess their relationships with one another. The relationship of air temperature with other thermal indexes is statistically significant ($p < 0.05$), with moderate to strong correlations as shown in Fig. 5 and the list of regression equations in Table 7. The correlations imply that the measured thermal indices were subject to the similar influence, and any one of them is acceptable for analysis. The operative temperature was selected as the thermal index for further analysis, similar in preceding studies [26,54,55].

Table 6
Summary of indoor thermal environment conditions.

Set point	*N*	Var.	T_a (°C)	T_g (°C)	T_{mrt} (°C)	T_{op} (°C)	*RH* (%)	AH (g_v/kg_{da})	V_a (m/s)
Original	167	Mean	23.1	23.4	23.8	23.4	61	13.1	0.21
		Min.	20.1	20.6	20.9	20.6	48	7.8	0.03
		Max.	26.9	27.1	27.4	27.1	79	15.8	0.73
		SD.	1.4	1.3	1.4	1.3	7	2.0	0.12
Original −2 °C	169	Mean	20.6	21.0	21.7	21.1	59	10.9	0.23
		Min.	17.5	18.0	18.2	18.0	49	6.6	0.02
		Max.	23.4	23.7	24.8	23.9	75	12.2	0.63
		SD.	1.3	1.3	1.4	1.3	5	1.4	0.11
Original +2 °C	156	Mean	26.1	26.2	26.3	26.2	63	15.9	0.18
		Min.	22.7	23.1	23.0	23.0	45	9.7	0.02
		Max.	28.6	28.6	29.6	28.6	81	18.0	0.70
		SD.	1.0	1.0	1.1	1.0	8	2.0	0.12
MS standard	149	Mean	24.3	24.5	24.7	24.5	61	13.9	0.18
		Min.	22.9	22.9	22.7	23.0	47	9.0	0.02
		Max.	25.3	25.5	26.2	25.5	80	15.5	0.55
		SD.	0.6	0.6	0.6	0.7	8	1.7	0.11

Note: *N*: Number of data; Min.: Minimum, Max: Maximum, SD.: Standard deviation; T_a: Indoor air temperature; T_g: Indoor globe temperature; T_{mrt}: Indoor mean radiant temperature; T_{op}: Indoor operative temperature; RH: Indoor relative humidity; AH: Indoor absolute humidity; V_a: Indoor air velocity.

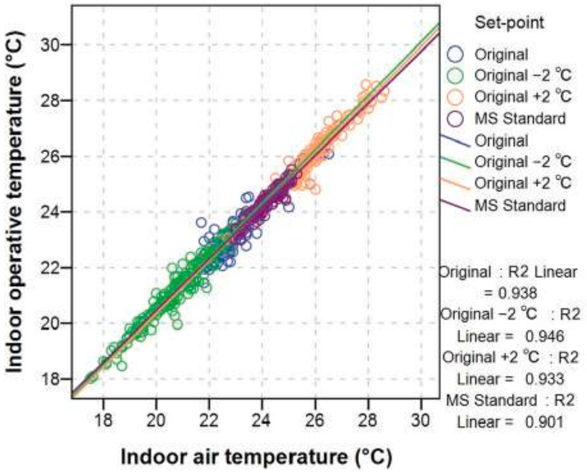


Fig. 5. Scatter plot of T_{op} against T_a with regression lines.

Table 7
Regression equations of thermal indices.

Set point	N	Equation	R^2	Equation	R^2	Equation	R^2
Original	167	$T_g = 0.93T_a + 1.95$	0.94	$T_{mrt} = 0.83T_a + 4.58$	0.66	$T_{op} = 0.93T_a + 1.83$	0.94
Original −2 °C	169	$T_g = 0.96T_a + 1.17$	0.96	$T_{mrt} = 0.92T_a + 2.84$	0.72	$T_{op} = 0.97T_a + 1.13$	0.95
Original +2 °C	156	$T_g = 0.96T_a + 1.18$	0.94	$T_{mrt} = 0.90T_a + 2.85$	0.67	$T_{op} = 0.96T_a + 1.16$	0.93
MS standard	149	$T_g = 0.95T_a + 1.51$	0.90	$T_{mrt} = 0.83T_a + 4.48$	0.54	$T_{op} = 0.93T_a + 1.86$	0.90

Note: N: Number of samples, T_a: Indoor air temperature (°C), T_g: Indoor globe temperature (°C), T_{mrt}: Indoor mean radiant temperature (°C), T_{op}: Indoor operative temperature (°C), R^2: Coefficient of determination.

3.2. *Indoor air temperature and AC settings*

The indoor air temperatures were manipulated in Original ±2 °C and MS Standard set-points through sets of air conditioner settings. Based on Table 8, the relationships between the indoor air temperature and AC settings used during the field study were statistically significant ($p < 0.001$). The variations of the indoor air temperature were up to 4 °C in each AC setting used, and the relationship was proportional, as illustrated in the scatter plot in Fig. 6.

3.3. *Thermal comfort zone*

In evaluating the thermal comfort zone in university office buildings, ordinal regressions were performed using probit analysis as the link function and the operative temperature as the covariate, following a similar method in preceding studies in AC office buildings [26,43,56]. The linear relationships (probit equation) in Table 9 were then used to calculate the mean operative temperature by dividing the constant by its coefficient and computing the probit proportion of each vote (P) based on Eq. (3) given as follows:

$$Probability = CDF.NORMAL\ (quant,\ mean,\ S.D.) \tag{3}$$

Table 8
Regression between the indoor air temperature and AC settings.

Location	N	Equation*	R^2	$S.E$
KL1	173	$T_a = 0.54T_s + 11.4$	0.83	0.019
KL2	119	$T_a = 0.60T_s + 9.0$	0.83	0.025
KL3	172	$T_a = 0.70T_s + 6.5$	0.82	0.025
SA1	132	$T_a = 0.44T_s + 13.0$	0.82	0.018
SA2	27	$T_a = 0.41T_s + 13.4$	0.92	0.024
All	628	$T_a = 0.56T_s + 10.2$	0.78	0.012

Note: N: Number of samples, R^2: Coefficient of determination, $S.E.$: Standard error of the regression coefficient, p: Significance level of the regression coefficient, T_a: Indoor air temperature (°C), T_s: AC settings (°C), *: All regression coefficients are statistically significant (p<0.001).

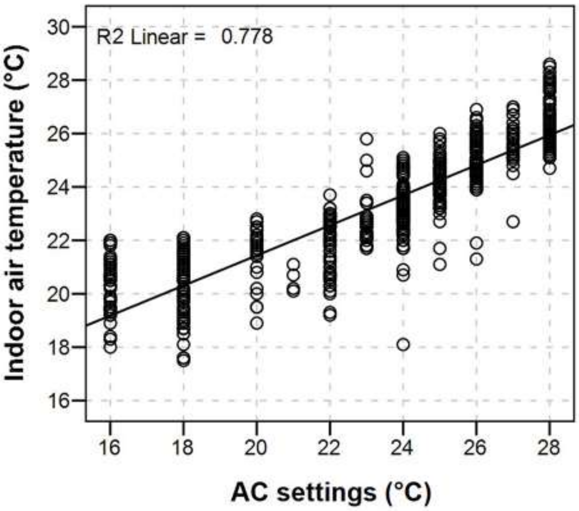


Fig. 6. Scatter plot of AC settings against the indoor air temperature.

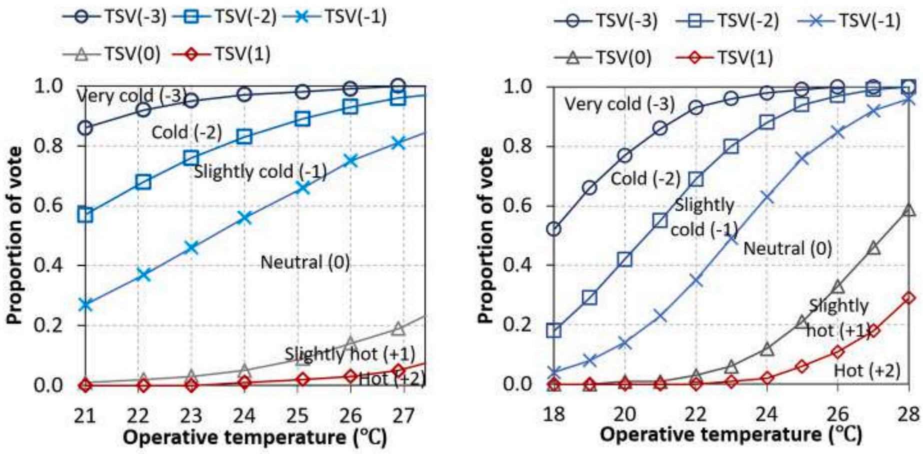
Table 9
Probit analysis of *TSV* and indoor operative temperature.

Set-point	Probit Equation	Mean T_{op} (°C)	*S.D.*	*N*	R^2	*S.E.*	*p*
Original	$P(\leq -3) = 0.258T_{op} + 4.219$	16.4	3.875	167	0.090	0.065	<0.001
	$P(\leq -2) = 0.258T_{op} + 5.134$	19.9					
	$P(\leq -1) = 0.258T_{op} + 5.940$	23.0					
	$P(\leq 0) = 0.258T_{op} + 7.698$	29.8					
	$P(\leq 1) = 0.258T_{op} + 8.434$	32.7					
All	$P(\leq -3) = 0.351T_{op} + 6.282$	17.9	2.846	628	0.335	0.023	<0.001
	$P(\leq -2) = 0.351T_{op} + 7.236$	20.6					
	$P(\leq -1) = 0.351T_{op} + 8.104$	23.1					
	$P(\leq 0) = 0.351T_{op} + 9.589$	27.3					
	$P(\leq 1) = 0.351T_{op} + 0.389$	29.6					

Note: $P(\leq -3)$: Probit proportion of *TSV* votes that are less than −3; $P(\leq -2)$: Probit proportion of *TSV* votes that are less than −2, $P(\leq -1)$: Probit proportion of *TSV* votes that are less than −1 and so on; T_{op}: Indoor operative temperature (°C); *S.D.*: Standard deviation; *N*: Number of samples; R^2: Coefficient of determination; *S.E.*: Standard error of regression coefficient.

where, *CDF.NORMAL* is the cumulative distribution function for normal distribution, *quant* is the operative temperatures in °C, and *S.D.* is the standard deviation. The probit analysis was only significant in the Original set-point ($p < 0.001$), where no experimental manipulation of AC settings was involved. Nevertheless, the combined data for all set-points were found to be significant. The probit equations were then translated into five curves that divide the proportional areas of *TSV* illustrated in Fig. 7 for each set-point and the combined data. The highest curve outlines 'Very cold' (−3) at the top, followed by 'Cold' (−2), 'Slightly cold' (−1), and so forth down to the lowest curve, 'Hot' (+2). The probit proportion in the Original set-point and the combined data were comparable, though the curves were steeper in the Original set-point. As operative temperature increases, the vote proportion for the cooler votes decreases and vice versa for the hotter votes. The outcome is in line with previous studies in Malaysia and the subtropical region in China [17,26]. Overall, 'Hot' (+2) votes started rising at the indoor operative temperature of 23 °C while 'Cold' (−2) votes depleted at 26 °C. The comfortable vote curve shown in Fig. 8 was estimated by transforming the probit proportion that accounts for the comfort zone ($-1 \leq TSV \leq 1$) [8].

In this study, the optimum proportion in the Original set-point was 67% when the operative temperature was between 25.6 and 26.5 °C. However, as a whole, the comfort zone peaked at 74% when the operative temperature was 26.2 °C, closest to its mean values during the Original +2 °C set-point. The comfort proportions of past studies conducted in office buildings with AC systems in Malaysia and China [26,43] were plotted together (Fig. 8). A field study in Kuala Lumpur by Damiati et al. [26] estimated about 86% optimum comfort at 27.0 °C, while Wu et al. [43] approximated 94% at 26.5 °C. The optimum comfort proportion in this study was lower as there was an intervention of temperature settings. The neutral temperature was similar, with less than 1 °C Celsius difference.



(a) (b)

Fig. 7. Proportion of *TSV* votes with the indoor operative temperature in each set-point; a) Original and b) combined data.

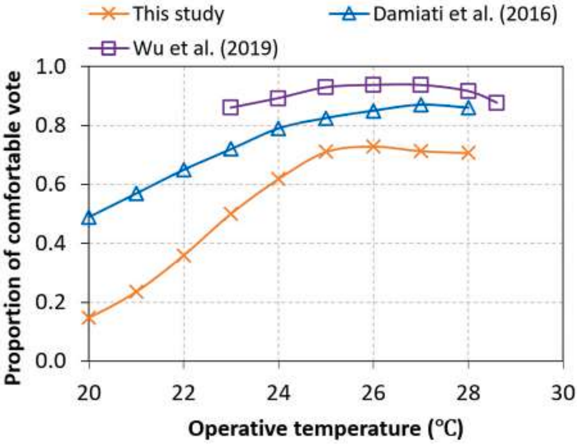


Fig. 8. Proportion of comfortable votes with relevant studies.

3.4. Comfort temperature

3.4.1. Griffiths' method

Due to discrete dependant variables, comfort temperature (T_c) is estimated via Griffiths' method using Eq. (4) [57–59]:

$$T_c = T_{op} + \frac{0 - TSV}{\alpha} \quad (4)$$

where T_{op} is the indoor operative temperature (°C), 0 refers to a neutral condition or can be replaced with any value denoting a neutral

Table 10
Comparison of the Griffiths' comfort temperature with 'neutral' and 'comfortable' votes.

Set-point	Griffiths' method			*TSV* = 0			*TP* = 0			*OC* = 5 or 6		
	N	Mean T_{cop}	*SD.*	*N*	Mean T_{op}	*SD.*	*N*	Mean T_{op}	*SD.*	*N*	Mean T_{op}	*SD.*
Original	167	24.7	2.0	79	23.4	1.3	79	23.5	1.3	58	23.6	0.5
Original −2 °C	164	24.0	2.2	29	21.1	1.3	57	21.7	1.2	44	21.6	0.5
Original +2 °C	150	25.1	2.1	67	26.2	1.0	61	26.1	1.2	43	26.2	0.5
MS Standard	147	24.9	1.7	80	24.5	0.6	77	24.5	0.5	56	24.5	0.5
All	628	24.6	2.1	255	24.3	1.8	274	24.0	1.8	260	23.9	2.0

Note: *N*: Number of samples; T_{cop}: Comfort operative temperature (°C); T_{op}: Indoor operative temperature (°C); *SD.*: Standard deviation; *TSV*: Thermal sensation vote; *TP*: Thermal preference; *OC*: Overall comfort.

sensation, and α is the Griffiths' constant, equivalent to the regression coefficient. Nicol and Humphreys [60] suggested that the constant value must exceed 0.40, and there are three constant values typically used as regression coefficients in calculating comfort temperatures; 0.25, 0.33, and 0.50. This study estimated Griffiths' comfort temperatures using a constant, $\alpha = 0.50$ according to Humphreys et al. [61]. The mean comfort operative temperature was approximated at 24.6 °C, and for each set-point, the mean comfort temperature ranges from 24.0 °C (for Original −2 °C) to 25.1 (for Original +2 °C). Table 10 shows the comparison of the Griffiths' comfort temperature with the mean operative temperature under three circumstances; when respondents voted 'neutral' thermal sensation ($TSV = 0$), 'no change' thermal preference ($TP = 0$), 'moderately comfortable', and 'very comfortable' overall comfort ($OC = 5$ or 6). At the neutral thermal sensation vote, the mean operative temperature was 24.3 °C, while there was no change in thermal preference and comfortable overall comfort, the mean operative temperatures were 24.0 and 23.9 °C, respectively.

3.4.2. Comparison with existing research

The mean operative temperatures associated with the 'neutral' and 'comfortable' votes showed similar results to the Griffiths' comfort temperature, following past studies done in mechanically-cooled buildings in Kuala Lumpur [26,54,55]. The findings of this study are compared to those of similar existing studies on thermal comfort in air-conditioned office buildings in Malaysia and other countries with tropical and sub-tropical climates, as presented in Table 11. The comfort temperature obtained in this study (24.6 °C) was most similar to studies done in Singapore, Thailand, Mexico, and Qatar, which estimated the comfort temperatures of 24.8 °C, 24.0 °C, 24.7 °C, and 24.0 °C, respectively [27,31,33]. Compared to a study done in the same universities in Kuala Lumpur and Shah Alam by Damiati et al. [26], the mean comfort temperature in this study was 1 °C lower. The slight variation may be due to the different approaches taken in this study, where the thermal environment was partially controlled unlike in the previous study. All in all, the mean comfort temperatures in all temperature set-points via Griffiths' method in this study were within the range of earlier studies in office buildings under tropical and subtropical climates which estimated the comfort temperature between 24.0 and 26.9 °C.

3.4.3. Comparison with related standards

The comfort bandwidth for heated and cooled buildings in the CIBSE guide estimates the relationship between comfort temperatures (T_c) and the daily running mean outdoor temperature (T_{rm}), as shown in Eq. (5).

Table 11
Comparison of comfort temperatures in offices with existing studies in the tropics and subtropics via Griffiths' method.

Reference	Climate	Location	*N*	Thermal index	T_c (°C)
This study	Tropical	Malaysia	628	T_{op}	24.6
Indraganti et al. [32]	Subtropical	India	4310	T_g	26.4
Damiati et al. [26]	Tropical	Malaysia	1114	T_{op}	25.6
		Indonesia	91	T_{op}	26.3
		Singapore	14	T_{op}	26.4
de Vecchi et al. [25]	Subtropical	Brazil	1274	*SET*	23.3
Mustapa et al. [24]	Tropical	Malaysia	108	T_{op}	26.1
Maykot et al. [44]	Tropical	Brazil	2080	T_{op}	24.0–25.1
Wu et al. [29]	Subtropical	China	460	T_{op}	26.8
Indraganti and Boussaa [31]	Subtropical	Qatar	3742	T_g	24.0
Wu et al. [17]	Subtropical	China	442	T_{op}	26.9
López-Pérez et al. [33]	Subtropical	Mexico	293	T_{op}	24.7
Sikram et al. [27]	Tropical	Singapore	1253	T_{op}	24.8
		Thailand	2197	T_{op}	24.0

Note: *N*: Number of samples, T_{op}: Operative temperature (°C), T_g: Globe temperature (°C), *SET*: Standard effective temperature, T_c: Comfort temperature (°C).

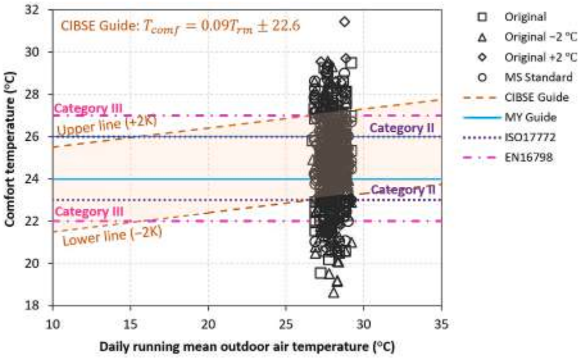


Fig. 9. Comparison of estimated comfort temperatures with relevant standards.

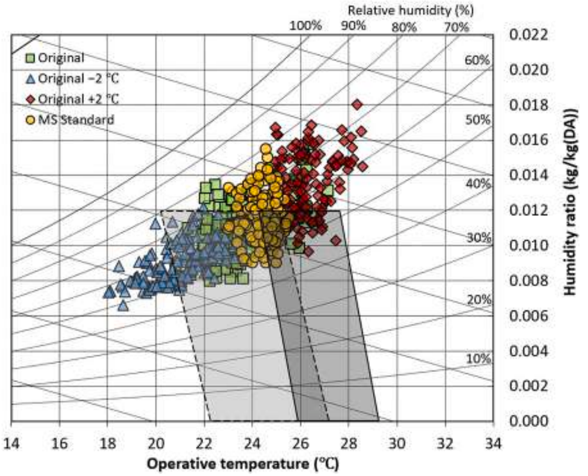


Fig. 10. Psychrometric chart based on ASHRAE Standard 55–2017 [8] graphic comfort zone.

$$T_c = 0.09T_{rm} \pm 22.6 \tag{5}$$

Comfort temperatures obtained via the Griffiths' method were plotted against the daily running mean outdoor temperature in Fig. 9 to be compared with the CIBSE guide (Eq. (5)). The adaptive model for mechanically-ventilated buildings in the CIBSE guidelines uses the daily running mean outdoor air temperature. Although the rest of the standards (ISO17772, EN16798, and MS 1525) were not adaptive models, they were consolidated in a single figure for thorough comparison with comfort temperatures in similar fashion with preceding studies by Damiati et al. [26] and Khalid et al. [55] in AC buildings. The comfort temperatures were spread out evenly between set-points and were located inside and outside the upper and lower limits, ±2 K based on the CIBSE guidelines. Overall, about 64% of the data were within the CIBSE guideline, and 24% were below the lower limit.

Similarly, there were variations within, above, and below the local standard MS1525 (24.0–26.0 °C), but only 36% lies within the Malaysian guideline. Almost 40% of the results were below the minimum recommendation, indicating an overestimation of the local comfort temperature. Although the mean comfort temperature (24.6 °C) was still within the local guideline, the data points imply that there may need to be a transition towards a lower minimum recommended temperature in the Malaysian policy in consideration of thermal comfort.

For comparison with ISO17772, Category II (normal expectation level) is selected while Category III (moderate expectation) for existing buildings is chosen for EN16798. EN16798 has a wide indoor temperature range (22.0 °C–27.0 °C), where 77% of data lies within the recommendation range. ISO17772 (23–26 °C) had about 51% within the temperature guideline. Due to the broader temperature range, the international standards ISO17772, EN16798, and CIBSE have a higher compliance rate than the local standard, MS1525.

The measured data, namely operative temperature and humidity ratio were plotted on the psychrometric chart in Fig. 10 based on the ASHRAE Standard 55 graphical comfort zone with a humidity ratio limit of 0.012 $\mathrm{kg/kg_{DA}}$ [8]. As the relative humidity decreases with the operative temperature, the Original −2 °C set-point had the most data below 0.012 $\mathrm{kg/kg_{DA}}$ (99%), while the Original +2 °C had the least with only 26%. Meanwhile, the results were below the ASHRAE humidity limit for the Original and MS Standard set-points at about 77% and 59%, respectively. Overall, the Original and Original −2 °C set-point results were mainly concentrated in the comfort zone with 1.0 *clo*, while the MS Standard and Original +2 °C results were focused on the 0.5 *clo* zone. These findings were consistent with a previous study in subtropical Hong Kong by Fang et al. [62], concluding that the thermal environment of the air-conditioned space was cooler rather than warmer. The ASHRAE comfort chart shown in this study is comparable to the AC building in China's hot and humid climate, with data points located within and beyond the ASHRAE comfort zone [43].

3.5. Preferred temperature

3.5.1. Thermal sensation vote and thermal preference

The frequency distribution of *TSV* in Fig. 11 shows neutral (0) vote proportions were the highest in the MS Standard set-point, with less than 10% of votes beyond the comfort zone. The smallest proportion of neutral votes was in the Original −2 °C set-point with less than a 20% ratio. The Original set-point was the second highest in terms of neutral votes, and it demonstrates that respondents felt cooler than warm in their everyday thermal environment. None of the respondents voted 'hotter sensation' in the Original −2 °C set-point, but there was a small proportion of 'cooler' votes when the indoor temperature was raised in the Original +2 °C set-point. The overall rank of the comfort zone portion ($-1 \le TSV \le 1$) from highest to lowest are MS Standard, Original +2 °C, Original, and Original −2 °C set-points. More than 70% of occupants accepted their thermal surroundings in all set-point temperature conditions. The highest thermal acceptance was 92.5% when the indoor air temperature was set at approximately 24 °C during the MS Standard set-point, and the lowest was 74.4% in the Original −2 °C set-point. It is apparent in Fig. 12 that occupants who preferred no change in their thermal preferences also find their thermal surroundings acceptable. There were inconsistencies in the Original and Original −2

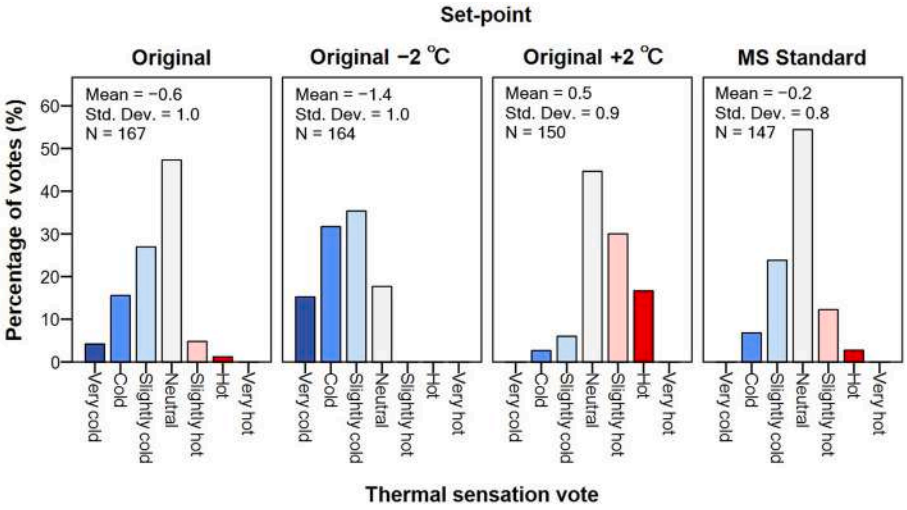


Fig. 11. Distribution of thermal sensation vote (*TSV*).

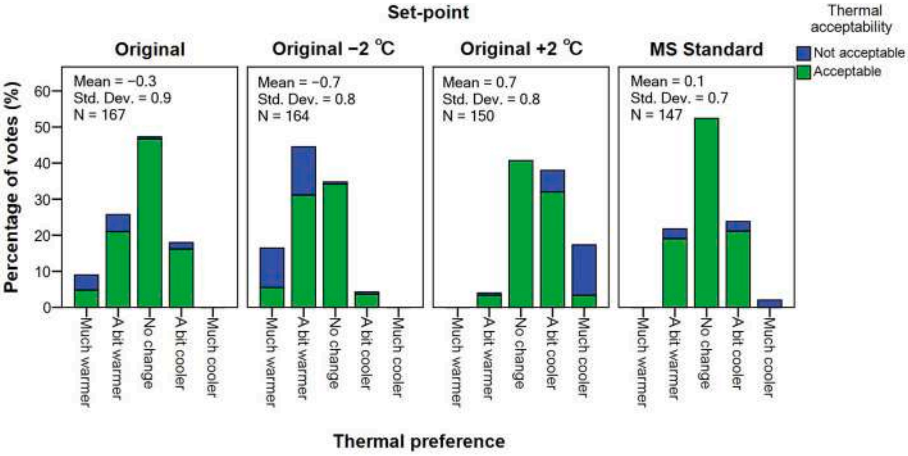


Fig. 12. Distribution of thermal preference (*TP*) and thermal acceptability (*TA*) votes.

°C set-points where occupants did not accept their thermal surroundings despite voting "No change" in *TP*, though these votes were less than 1%.

The mean thermal sensation vote depicted that only the Original −2 °C set-point had values outside the comfort zone (mean $TSV = -1.4$) with the 'warmer' thermal preference in response to the 'cooler' votes. In typical settings (Original set-point), a slightly warmer tendency was observed with cooler sensation on average. The results came close to a previous study on AC buildings in the tropical climate countries of Malaysia, Indonesia, and Singapore by Damiati et al. [26]. As expected, the elevation of air temperature in the Original +2 °C set-point causes a mainly 'warmer' sensation, thus warrants a 'slightly cooler' thermal preference. There was only a 0.1 scale change between the thermal sensation vote and thermal preference in the MS Standard set-point, supporting the overall comfort zone rank. The correlation between the mean thermal preference and the mean thermal sensation vote illustrated in Fig. 13 is strong with the coefficient determination, R^2 of 0.81. The linear relationship between thermal preference and thermal sensation votes was

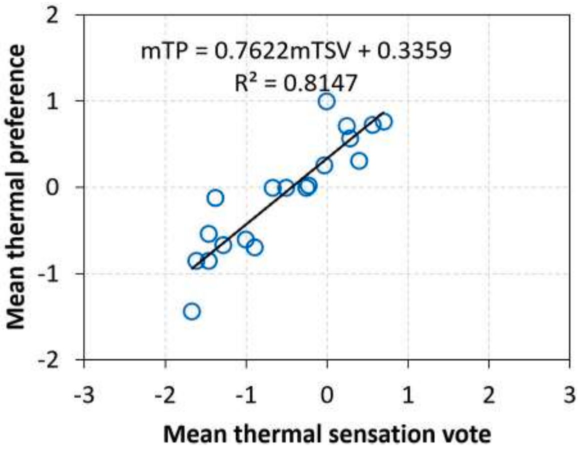


Fig. 13. Correlation of mean thermal preference and mean thermal sensation votes.

Table 12
Probit analysis of the preferred temperature.

Set-point	Probit Equation	Mean T_{op} (°C)	*S.D.*	*N*	R^2	*S.E*
Original	$P(cooler) = 0.23T_{op} + 6.21$	27.0	4.444	167	0.04	0.084
	$P(warmer) = 0.30T_{op} + 6.51$	21.9	3.367	167	0.07	0.086
All	$P(cooler) = 0.51T_{op} + 12.16$	23.9	1.968	628	0.16	0.047
	$P(warmer) = 0.37T_{op} + 8.10$	22.0	2.718	628	0.24	0.031

Note: T_{op}: Operative temperature; *SD.*: Standard deviation (°C); *N*: Number of samples; R^2: Coefficient of determination; *SE*: Standard error.

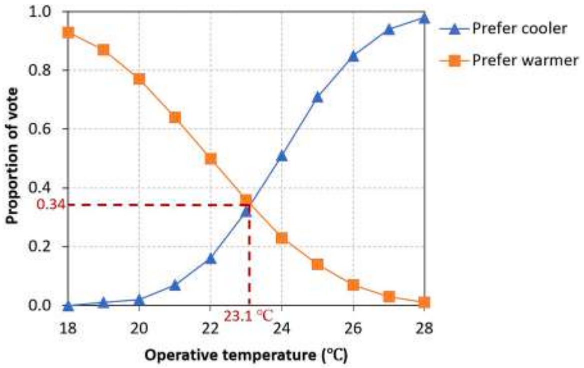


Fig. 14. Proportion of the preferred temperature of combined data.

directly proportional, denoting that occupants prefer a cooler environment when feeling warmer.

3.5.2. Mean preferred temperature

The preferred temperature can determine the occupants' expectations of the existing thermal environment. In this study, the

Table 13
Comparison of the preferred temperature with existing studies.

Reference	Climate	Location	Building type	Thermal index	T_c (°C)	T_P (°C)
This study	Tropical	Malaysia	University office	T_{op}	24.6	23.1
Hwang et al. [42]	Tropical	Taiwan	Office	*ET*	25.8	23.8
Wu et al. [43]	Subtropical	China	Office	T_{op}	26.9	26.0
De Vecchi et al. [25]	Subtropical	Brazil	Office	*SET*	23.3	25.8

Note: T_c: Comfort temperature; T_p: Preferred temperature; T_{op}: Operative temperature (°C); *ET*: Effective temperature (°C); *SET*: Standard effective temperature (°C).

preferred temperature was estimated via probit analysis set up in two modes; "prefer cooler" when respondents voted cooler thermal preference ($TP \geq 1$) and "prefer warmer" when respondents voted warmer thermal preference ($TP \leq 1$). The probit model was implemented to obtain the least thermal preference votes for either cooler or warmer environment. Then, the possible temperatures with no change in the preference will be stated. Like estimating comfort temperature, ordinal regression was performed on a dependent variable, thermal preference (*TP*), with probit as the link function and operative temperature as the covariate. The regression coefficient was divided by its constant to calculate the mean operative temperature. The standard deviation of the cumulative normal distribution was the inverse value of the probit regression coefficient.

The significant results of probit analysis in the Original set-point and the combined data are presented in Table 12. The probits were transformed into proportion and plotted as two curves in Fig. 14 depicting the cooler and warmer preferences; thus, the intersecting point was the preferred temperature. The preferred temperature in the Original set-point was 23.5 °C, with 21% of responses preferring different temperatures. Consequently, the overall preferred temperature was 23.1 °C, with only 34% of reactions wanting a temperature change (see Fig. 14).

A comparison of the preferred temperature estimated in this study with similar research in tropical and subtropical countries is listed in Table 13 involving non-residential buildings. In this study, the preferred temperature was 1.5 °C lower than the comfort temperature (24.6 °C), implying an inclination of a cooler environment despite already being in thermally comfortable conditions. These findings were consistent with studies in office buildings in the subtropical city in China [43] and Taiwan [42], where the preferred temperature was found to be slightly lower than the estimated comfort temperature. However, in Brazil, the preferred temperature was more than 2 °C higher [25].

3.5.3. The linear relationship between preferred and comfort temperatures

Regression analysis was used to examine the connection between preferred and comfort temperatures. In this analysis, the preferred temperature (T_P) was assumed to be the operative temperature when respondents preferred no change ($TP = 0$) and plotted with the corresponding Griffiths' comfort temperature, as illustrated in Fig. 15. A total of 274 samples were analyzed. The significant

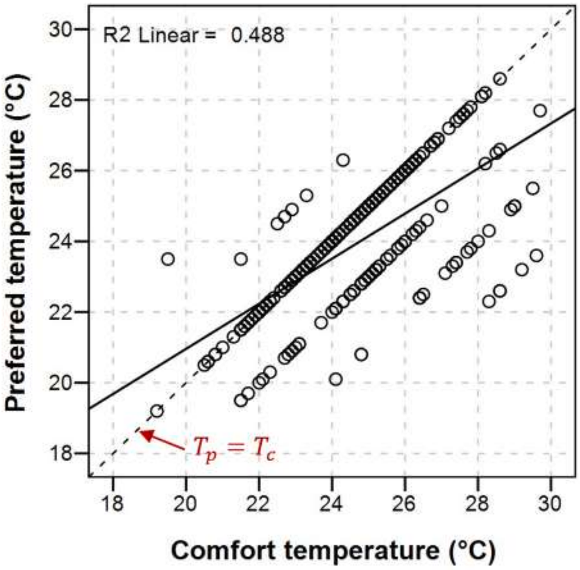


Fig. 15. Scatterplot between the preferred temperature (TP = no change) and the Griffiths' comfort temperature with the regression line.

Table 14
Regression analysis between preferred and comfort temperatures.

Reference	Country	Regression equation	*N*	R^2	*S.E.*
This study	Malaysia	$T_P = 0.64T_c + 8.21$	274	0.50	0.040
Shahzad and Rijal [41]	Japan	$T_P = 0.769T_c + 5.8$	2929	0.70	0.009
	Norway	$T_P = 0.441T_c + 13.4$	103	0.40	0.054
	UK	$T_P = 0.315T_c + 16.5$	64	0.31	0.059

Note: T_P is preferred temperature, T_c is comfort temperature, *N* is the number of data, R^2 is the coefficient of determination, *SE* is the standard error of regression.

relationship between preferred and comfort temperatures is presented in Table 14 alongside a current study by Shahzad and Rijal [41], where the regression coefficient was similar. The preferred temperature via regression was estimated at 23.9 °C when the comfort temperature is 24.6 °C, alluding that the respondents preferred a lower temperature despite feeling comfortable in the existing thermal environment. Nevertheless, the results presented as linear relationships in this study are consistent with those of the previous studies conducted in seasonal countries of Japan, Norway, and the United Kingdom. Conclusively, the results also agreed with the estimation via the probit method in the previous section, where the preferred temperature was 1.5 °C lower than the comfort temperature.

4. Conclusions

This study investigated thermal comfort under the four set-point temperature conditions (Original, Original ±2 °C, and MS Standard) in Malaysian university offices. The concluding statements are as follows:

1. The mean operative temperature for the Original, Original −2 °C, Original +2 °C, and MS Standard set-points was 23.4 °C, 21.1 °C, 26.2 °C, and 24.5 °C, respectively. Statistically, the highest portion of comfort zone votes was recorded during the MS Standard set-point.
2. The comfort temperature estimated in the Original, Original −2 °C, Original +2 °C, and MS Standard set-points were 24.7 °C, 24.0 °C, 25.1 °C, and 24.9 °C, respectively. Altogether, the comfort temperature was 24.6 °C which is higher than the mean operative temperature in the Original set-point but closest to the MS Standard set-point.
3. About 64% of the estimated comfort temperature resides within the upper and lower limits (±2 K) in the CIBSE guidelines for mechanically-cooled buildings, while only 36% of data were within Malaysian standard MS1525 (24 to 26 °C). However, 63% met the minimum temperature guideline. Although the mean comfort temperature in this study (24.6 °C) complied with the minimum Malaysian standard limit, the findings from various data points may imply that transitioning to a lower recommended temperature in the local standard could be necessary to consider occupants' comfort.
4. Overall, the preferred temperature was 23.1 °C, where merely 34% of responses wanted a temperature shift. The relationship between preferred and comfort temperatures was significant, and at a comfort temperature of 24.6 °C, the preferred temperature was approximated at 23.9 °C. The outcome indicates that the lower ambient temperature was desirable for respondents even at a thermally comfortable state.

Following the results from variations of set-point temperature conditions in this study, the mean operative temperature in the Original set-point was 23.1 °C which was lower than the minimum recommendation of MS1525, indicating non-compliance in the typical day-to-day set-point. Interestingly, the MS Standard set-point had the highest comfort zone votes. The estimated comfort temperature of the overall data was 24.6 °C, nearest to the minimum temperature recommendation from the local standard. The findings show that adherence to the Malaysian Standard for Energy Efficiency positively impacts the occupants' comfort level. The rate of comfort zone votes was also high when the air temperature was increased by 2 °C from the Original set-point. Considering that higher AC settings use less energy, the results in this study would indicate that energy-saving measures can be put into practice without necessarily compromising comfort.

While comfort temperatures are estimated based on neutral thermal sensation, preferred temperatures consider occupants' preferences to be in a non-neutral environment. The association of thermal comfort and preference revealed a significant gap between comfort and preferred temperatures. A cooler environment is generally desirable in a hot and humid climate, but there are instances where occupants want to be warmer. Therefore, this study suggests that utilizing the preferred temperature as the lower or upper limit of comfort in steady-state conditions could support the energy management in AC buildings. For example, the comfort threshold can be recommended at 23.1 °C, based on the calculated preferred temperature.

Several recommendations could be applied for future research to advance thermal comfort studies, specifically in AC office buildings in Malaysia. This study was conducted in Kuala Lumpur and Shah Alam, urban cities with a massive population per square kilometer. Malaysia has diverse weather conditions in the eastern and western regions in Peninsular Malaysia. Thus, a comprehensive study on multiple types of cities in Malaysia would be advantageous in discovering how acclimatization, including social and economic background, impacts thermal comfort. The AC settings were altered in this study to achieve the varying set-point conditions and analyze the subjective responses to find comfort temperature. As the energy consumption in AC-operated buildings is huge, it will be beneficial to determine the electricity expenditure when occupants are thermally comfortable. Additionally, the relationship between energy consumption and building characteristics could also be analyzed by factoring in thermal comfort.

CRediT author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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