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Investigation of Thermal Adaptation and Development of an Adaptive Model under Various Cooling Temperature Settings for Students' Activity Rooms in a University Building in Malaysia

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Abstract: The use of an air conditioner (AC) becomes essential, particularly in a hot and humid climate, to provide a comfortable environment for human activities. The setpoint is the agreed temperature that the building will meet, and the use of the lowest setpoint temperature to accelerate the cooling of indoor spaces should be avoided. A comprehensive field study was conducted under various cooling temperature settings in two student activity rooms in a university building in Malaysia, so as to understand respondents' characteristics and behavior toward AC usage, to estimate the comfort at various indoor temperatures, to develop an adaptive model of thermal comfort in AC spaces, and to compare the comfort temperature with related local and international indoor thermal environmental standards. The findings indicated that water intake and clothing insulation affected personal thermal comfort. Moreover, the mean comfort temperature for respondents was 24.3 °C, which is within an indoor thermal comfort zone of 23–27 °C. The findings suggest that the preference of occupants living in a hot and humid region for lower temperatures means that setting temperatures lower than 24 °C might underestimate the indoor comfort temperature. Additionally, an adaptive relationship can be derived to estimate the indoor comfort temperature from the prevailing outdoor temperature.

Keywords: university building; students' activity room; air conditioning; comfort temperature; adaptive model

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1. Introduction

1.1. Overview

The indoor thermal environment is part of the indoor environmental quality and is closely influenced by climatic conditions [1]. Thermal comfort deficiencies in buildings may affect occupants' well-being [2]. Building spaces in hot and humid climates are regularly uncomfortable due to high temperatures, relative humidity, and low air movement [3], leading to thermal discomfort in the indoor space. In hot and humid climates such as Malaysia and Singapore, the recommended temperature setting should be maintained between 24 and 26 °C [4,5]. Thailand's standards adhere to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards [6]—between 23 and

25 °C. However, indoor conditions are maintained based on design [4] and mode of cultural habits concerning climatic conditions [7].

The adaptations in any thermal condition primarily depend on a building's physiology, environment, and behavior [5,8], with a conservative state of response under unfavorable conditions. The neutral thermal sensation in a condition of feeling neither cold nor hot is widely used when applying the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55—a seven-point thermal sensation scale to assess thermal comfort [9]. People living in hotter climates tend to find lower temperatures to be thermally comfortable [7]. Hence, the implicit correlation of relevant local and international standards regarding the findings of the observed acclimatization of indoor comfort—especially for non-commercial buildings—needs to be sufficiently studied. In contrast, personal factors based on gender and body mass index, along with adaptive behaviors such as drinking water and clothing insulation, are commonly associated with a substantial impact on the thermal comfort parameter to improve indoor thermal comfort. However, none of these studies has determined the statistical significance of personal characteristics with respect to thermal comfort requirements. The objectives of the present study on AC usage at various setpoint temperatures were as follows:

1. To evaluate the effects of personal characteristics and adaptive behavior on thermal comfort.
2. To estimate comfort at various indoor temperatures in a student activity room space based on field survey data.
3. To develop an adaptive model of thermal comfort in AC spaces.
4. To compare the estimated comfort temperature with local and international indoor thermal environmental standards.

The common perception that using the lowest thermostat setting helps speed up cooling for indoor spaces is wrong. People living in hot and humid climates such as Malaysia [10] and Indonesia [11] tend to use AC at the lowest setpoint temperature. In this scenario, the occupants in the cooling space might desire the indoor air temperature to correspond to the setpoint temperature of the AC. There is a potential interaction between indoor thermal conditions and human habitual adaptive behavior, adjusting to a comfortable indoor environment according to the occupants' thermal expectations [12]. In addition, all government offices in Malaysia are urged to offset the AC temperature no lower than 24 °C, as stated in Malaysia Standard-MS1525 [13], to promote energy-efficient practices.

1.2. Significance of Study

The identified comfort temperature will represent the guidelines for the tolerable range of temperature settings for residential buildings equipped with AC in the living room in Malaysia. Enhanced indoor thermal comfort may improve the occupants' satisfaction and help to attain environmental sustainability. Therefore, from the health point of view, optimal satisfaction with the indoor thermal environment is vital, as the thermal conditions may potentially cause the improper function of human physiological processes. It is becoming essential to maintaining thermally comfortable conditions for a healthy indoor living environment and a holistic quality of life in urban environments.

2. Literature Review

Residential Buildings with AC Modes

The vernacular residential buildings in the hot and humid study region were developed and designed with passive cooling components based on prevailing winds and the buildings' orientation. However, the high demands of modern residential buildings have neglected the importance of local climatic conditions and the need for energy conservation. These have resulted in new buildings having overall poor thermal performance and the need for mechanical ventilation and AC, leading to a high energy consumption rate [4]. In the future, demand for AC usage is forecast to grow, which will drive a 30% increase in global electricity demand by 2050 [5]. ASHRAE defines thermal comfort as 'the state of mind which expresses fulfillment with the thermal condition' regarding climatic conditions, which drives occupants to experience the desired room comfort temperature. However, this might vary depending on activity, behavior, clothing insulation, and humidity [14]. Interventions originating from unfavorable thermal comfort could cause the occupants to feel unpleasant regardless of enhancing the condition of rooms [15]—for example, regulating AC setpoint temperatures to ensure appropriate thermal surroundings. A field study was conducted to facilitate the measurement of the thermal environment, and a survey was carried out for living rooms, with reference to residential buildings with AC cooling modes. A summary of previous studies of residential buildings with AC modes is presented in Table 1.

Table 1. Previous field studies for residential buildings with AC modes.

Reference	Country	Climate	Types of Residential Buildings	Number of Samples	Duration	Major Findings
Lin & Deng [16]	Hong Kong	Subtropical	High-rise	554	September 2002–May 2003	AC usage peaks during sleeping hours for more than 8 h, at a temperature between 20 and 22 °C
Kubota et al. [17]	Malaysia	Hot and humid	One-story terrace	800	September–October 2004, 2009	Occupants' AC usage behavior uses very low setpoints
Puangmalee et al. [18]	Thailand	Hot and humid	Experimental room	660	2015	The effect of thermal sensation is based on different set temperatures with various air-speed levels
Kim et al. [19]	Australia	Humid subtropical	Detached house	42	March 2012–March 2014	Occupants' tolerance in cooler temperature conditions in relation to outdoor temperature
Zaki, Hagishima, et al. [10]	Malaysia	Hot and humid	Low-cost apartment	38	September 2013–May 2015	The trend of AC usage peaked at night, caused by thermal discomfort
Zaki et al. [20]	Malaysia	Hot and humid	Low-cost apartment	63	September 2013–May 2015	The habitual behavior of occupants to turn on the AC during sleeping hours
KC et al. [21]	Japan	Warm and temperate	Condominium	18	September 2016–October 2016	The preference to adjust to adaptive behaviors such as opening windows and using fans
Jaffar et al. [22]	Kuwait	Hot and humid	Home villa	250	March–October	Thermostat setpoints contributed to a significant effect, including the building insulation and glazing
de Dear et al. [23]	Australia	Humid subtropical	Detached house	42	March 2012–March 2014	The occupants were more tolerant of cooler temperatures
Lee and Shaman [24]	New York City	Humid subtropical	Apartments	180	September–October 2015	AC usage at night with an average temperature setting of 21.1 °C for 8 h
Yoshida et al. [25]	Thailand	Hot and humid	Detached house	32	2016 and 2017	The AC usage in urban areas is longer and more frequent due to the occupants' expectation of a comfortable lifestyle
Panraluk and Sreshthaputra [26]	Thailand	Hot and humid	Experimental room	28	March–May 2018	The overweight elderly in Thailand felt comfortable at operative temperatures within the range of 27–29 °C.

Table 1. *Cont.*

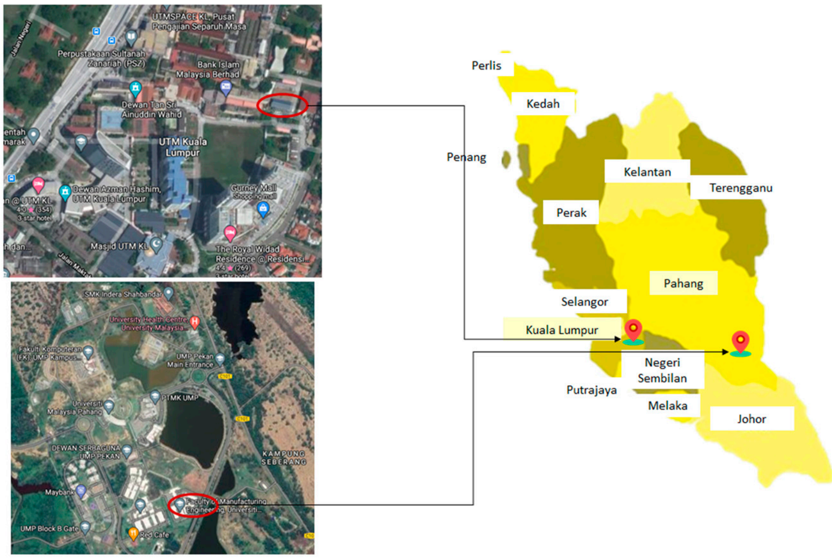
Reference	Country	Climate	Types of Residential Buildings	Number of Samples	Duration	Major Findings
Li et al. [27]	China	Hot and humid	Detached house	150	October 2013–December 2014	The range of temperature settings was found between 21 and 27 °C.
Aqilah et al. [28]	Malaysia	Hot and humid	Low-cost apartment	19	March 2016–August 2017	The occupants' trend of turning on the AC
Liu et al. [29]	China	Hot and humid	Detached house; multistory high-rise	38	March–June 2018	The AC operation is influenced by the occupants' thermal experience
Jeong et al. [30]	Australia	Humid subtropical	Detached house	42	March 2012–March 2014	The outdoor temperature affects the AC cooling behavior and the AC usage in living rooms
Sena et al. [31]	Malaysia	Hot and humid	Multistory	214	November 2017–January 2018	AC usage is among the factors affecting electricity consumption; most used temperature settings were between 19 and 25 °C
Ramos et al. [32]	Brazil	Humid subtropical	Multistory	3, 259	October 2018–January 2019	The average duration of AC usage in living rooms was 9 h, with a temperature setting of 21 °C
Malik et al. [33]	Mumbai	Tropical	Multistory	705	January, May, August, and September	Adaptive behavior of opening windows and doors was correlated with indoor humidity, while ceiling fan usage was correlated with indoor globe temperature and humidity

This study's originality might be the findings with respect to the thermal environment under different set temperatures. Regardless, the objective of the experiment was to explore the thermal comfort conditions in living rooms, where people are relaxed and exhibit a sedentary manner of activity. This is similar to the environment and respondents' behavior in student activity rooms. The university building's cooling systems are regularly controlled by centralized air-conditioning systems, making it inconvenient for researchers to intrude on the learning process, due to relatively high temperature changes from 16 to 28 °C.

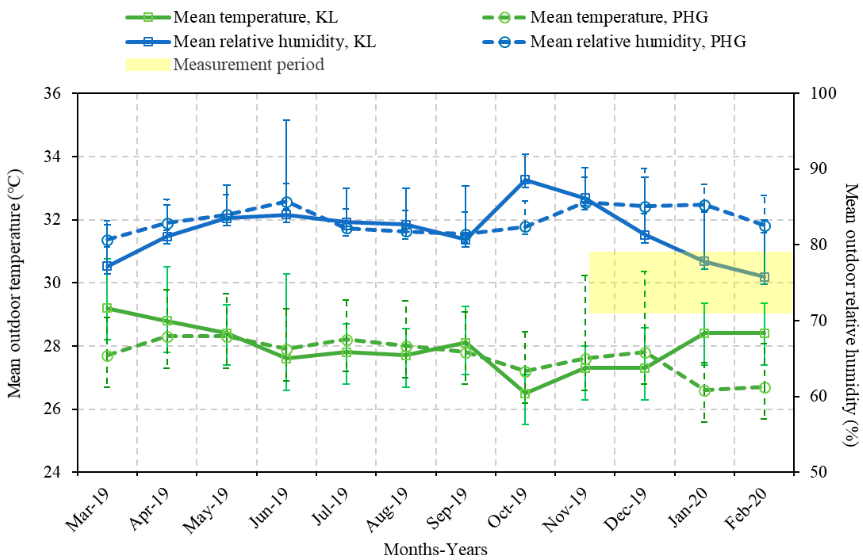
3. Methodology

3.1. Climate of the Studied Area

People who live in hot and humid climates must adapt to the climatic conditions, mainly characterized by high relative humidity (between 70 and 90%) and an ambient air temperature of 26 to 33 °C throughout the year [34]. This study compared the similar characteristics of two buildings at different locations that experience the same geographic conditions (i.e., landforms, environment, and human activities). Annual variation in monthly outdoor air temperature and relative humidity was assessed according to measurements taken from March 2019 to February 2020 at the weather station installed at a height of 68 m on the rooftop of the Malaysia–Japan International Institute of Technology (MJIIT) building, Universiti Teknologi Malaysia, Kuala Lumpur, as well as on the ground near the building of Fakulti Kejuruteraan Pembuatan at Universiti Malaysia Pahang, Pekan, Pahang. The readings of mean outdoor air temperature and relative humidity recorded in Kuala Lumpur (3.1729° N; 101.7209° E) were 28 °C and 81%, respectively, while in Pahang (3.5437° N, 103.4289° E) they were 27.5 °C and 83%, respectively, as shown in Figure 1.



(a)



(b)

Figure 1. (**a**) Location of study area and field measurement locations (source: Google Maps). (**b**) Monthly variation in outdoor temperature and outdoor relative humidity from March 2019 until February 2020. The error bars show the standard deviation.

3.2. Data Collection

Due to most residential buildings' occupants going out for school/college/work or related activities during the day, people prefer to be undisturbed in their private lives and avoid disruptive equipment installation around the house. Student activity rooms provided a convenient place to facilitate the thermal environment measurements and to carry out the survey.

The aggregated data collected were 252 valid samples from 63 voluntary university students from May 2019 to February 2020. The focus on young adults among university students might be advantageous, as they prefer lower temperatures compared to the elderly [35,36]. In addition, student samples are prevalent in psychological studies, as these groups have been established to provide moderately good estimates as representative samples [37]. However, only respondents in good health (i.e., not having the flu, cold, or fever, and currently not taking any medication) could proceed with the measurements. Field measurements and surveys were performed during the daytime between 8:00 and 17:00, subject to respondents' availability.

3.3. Thermal Measurement

Field physical measurements and thermal comfort surveys were performed simultaneously for each AC setpoint temperature case in two student activity rooms. The student activity rooms are equipped with a split AC unit, couch, and coffee table, with an area of approximately 24.8 m^2 and 13.8 m^2, respectively. All equipment is mounted on a custom-made pipe stand installed at a height of 0.7 m from the floor within a radius of 1.0 m [36–38], at the same height level as a normal sitting position. The studied building, its floor plan layout with the arrangement of the allowable seating locations and equipment (A–J refer to seating, while V refers to the location of the Kanomax hot-wire anemometer, and T1–T5 denote HOBO data loggers); the equipment setup, and photos of the respondents in the room are shown in Figure 2. The equipment details are presented in Table 2. All parameters of the indoor thermal environment were measured at 10 s intervals for an experimental period of approximately 45 min at each AC setpoint. The tips of the HOBO data logger sensors used to measure the air temperature were inserted into aluminum-foil-wrapped cups to improve their protection from direct radiation [39,40] and allow an accurate reading.

(**a**)

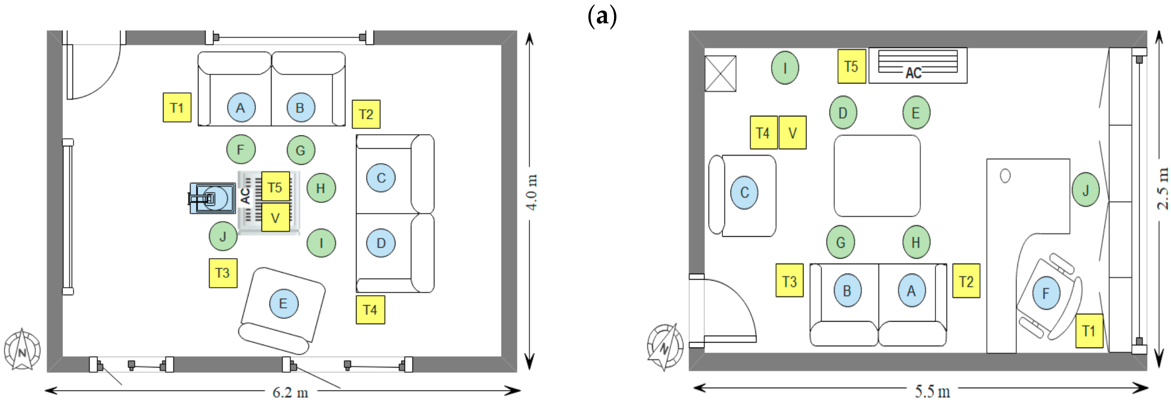


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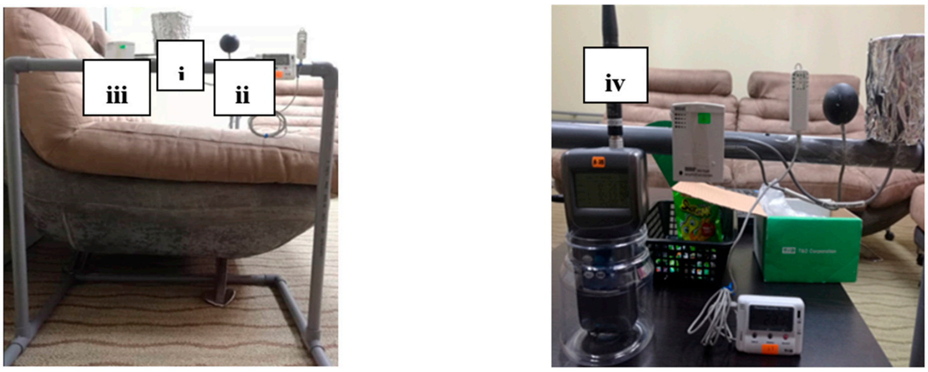
Figure 2. *Cont.*



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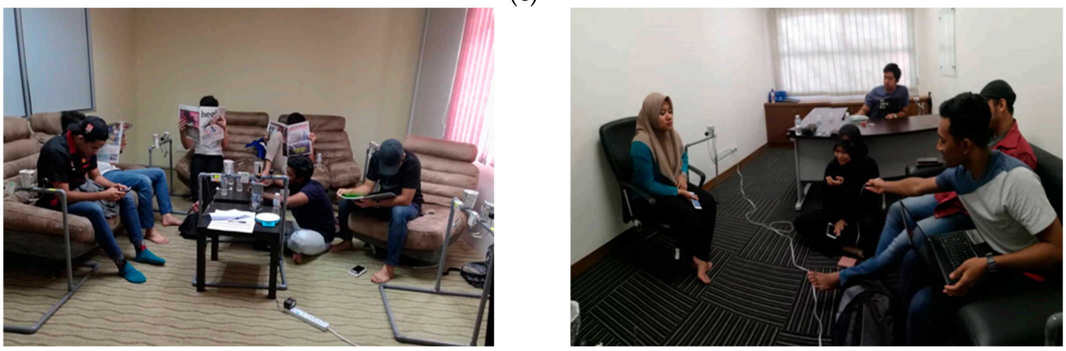

(**d**)

Figure 2. (**a**) Studied building, (**b**) floor layout, (**c**) equipment setup—(i) air temperature, T_a; (ii) globe temperature, T_g; (iii) relative humidity, *RH*; (iv) air speed, V_a—and (**d**) photos of respondents in the student activity rooms.

Table 2. Equipment details and specifications.

Equipment	Parameter Measured	Type of Sensor	Resolution Accuracy and Tolerance
HOBO thermo recorder, U12—U13	Air temperature	External sensor cable tmc1-hd + aluminum cup	0.03 °C ± 0.35 °C (0 to 50 °C)
	Globe temperature	External sensor cable tmc1-hd + 40 mm black sphere	
	Relative humidity	Internal sensor	0.03% ± 2.5% *RH* (10% to 90%)
Kanomax hot-wire anemometer 6501	Air speed	Needle probe 6542-2G	0.01 m/s ±(2% reading ± 0.0125) m/s (0.10 to 30.0 m/s)
Digital weighing scale	Water intake	Strain gauge	0.1—1 g

Respondents were exposed to setpoint temperatures of 16, 20, 24, and 28 °C in groups of 4–6 persons. Changing the current set temperature, wearing shoes, having a heavy meal, and exiting the room during the experiment were prohibited. Only certain low-intensity, passive physical activities were allowed (i.e., using a smartphone, reading, watching a movie or drama, having a low-volume chat, or sitting quietly). A 250 mL bottle of drinking water was provided and distributed to each respondent. Then, the amount of water intake was recorded. The data collected were analyzed using several statistical and analytical methods, which were determined through voting scales obtained from the physical and thermal measurements. The analysis method was performed using the International Business Machines (IBM) Statistical Package for Social Sciences (SPSS) software version 23. The two analytical methods used in this research to determine indoor comfort temperatures were Griffiths' method and probit analysis. In addition, correlations, psychometric charts, and chi-squared tests were also used to describe the relationships between the variables with respect to the relevant thermal comfort parameters. The detailed structure of the research methodology followed to achieve each study objective is illustrated in Figure 3.

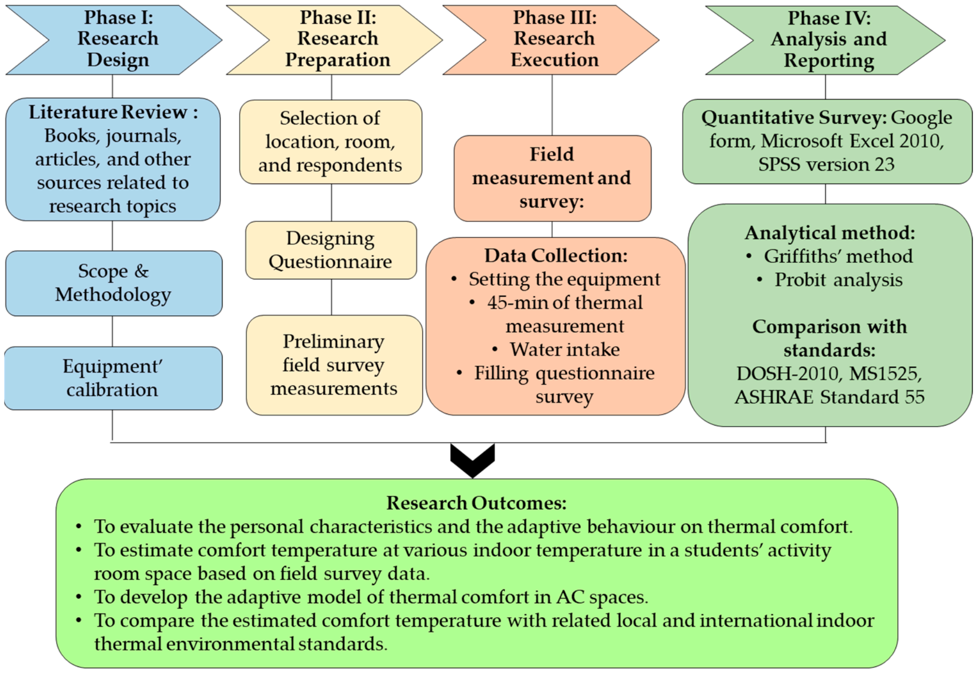

Figure 3. Structure of the research methodology.

3.4. Thermal Comfort Survey

This thermal comfort study was performed by administering a survey session to each group of students at the end of the experimental period before they left the room. The questionnaire survey, provided in English and accompanied by a Malay translation, was modified, improved, and compiled based on previous studies [41–43], as in Appendix A. The metabolic rate of the respondents was assumed to be 1.0 met, as only certain low-intensity physical activities could be performed throughout the experimental period. Post-occupancy evaluations (POEs) can be determined based on satisfaction with the indoor thermal environment. However, comprehensive aspects (e.g., lighting, indoor air quality, energy auditing) need to be considered in ensuring the possibility of meeting the buildings occupants' demands, resulting in continuous improvements in the quality of the building space. In addition, tool development needs to be carefully enhanced in Malaysia, as currently there is no properly formatted adapted survey form [44], as compared to the established methods in the United Kingdom, United States of America, Canada, and Australia [45], which may not apply equally in other countries. It can be inferred that human satisfaction in different climates is likely to vary due to cultural differences [46].

In this study, the thermal sensation vote (*TSV*), the ASHRAE seven-point scale [47], humidity sensation (*HS*) [48], and the air movement vote (*AMV*) [49] were the scales used, as shown in Table 3. Additionally, the Nicol five-point scale [42,43] was used to assess thermal preference (*TP*), a five-point scale was used to assess humidity preference (*HP*), and a six-point scale was used to express overall comfort (*OC*), as indicated in Table 4.

Table 3. The scale of thermal sensation vote, humidity sensation, and air movement vote.

Scale	Thermal Sensation Vote (*TSV*)	Humidity Sensation (*HS*)	Air Movement Vote (*AMV*)
−3	Very cold	Very dry	Very bad
−2	Cool	Dry	Bad
−1	Slightly cool	Slightly dry	Slightly bad
0	Neutral	Neutral	Neither bad nor good
1	Slightly warm	Slightly humid	Slightly good
2	Warm	Humid	Good
3	Very hot	Very humid	Very good

Table 4. The scale of thermal preference, humidity preference, and overall comfort.

Scale	Thermal Preference (*TP*)	Humidity Preference (*HP*)	Overall Comfort (*OC*)
6	-	-	Very comfortable
5	-	-	Moderately comfortable
4	-	-	Slightly comfortable
3	-	-	Slightly uncomfortable
2	Much cooler	Much drier	Moderately uncomfortable
1	A bit cooler	A bit drier	Very uncomfortable
0	No change	No change	-

4. Results and Discussion

4.1. Subject Characteristics

Groups of respondents consisting of university students (i.e., diploma, undergraduate, and postgraduate) participated in this study. By gender, the respondents were segregated into 42 (66.7%) males and 21 (33.3%) females. Their age range was only between 19 and 30 years old, with the mean age of respondents being within their 20 s. The range of ensemble clothing for females was between 0.19 and 0.54 *clo*, while the males were collectively between 0.14 and 0.47 *clo* (i.e., t-shirts, long trousers or shorts, and one-piece dresses). The body mass index data showed that almost 60% of the respondents had an ideal score—between 18.5 and 24.9 kg/m^2—while the rest were overweight based on the calculation of weight measured in kilograms divided by the square of height in meters.

4.2. Indoor Environmental Data

The measured thermal variables of air temperature, globe temperature, relative humidity, and air speed were obtained directly from the data logging equipment. The estimated parameters of mean radiant temperature, operative temperature, and absolute humidity were determined based on calculations made under various indoor thermal conditions. The results from field measurements and surveys were compiled. The descriptive statistics of mean values and the standard deviation of each parameter are presented in Table 5. The average indoor air temperature was measured only during the field measurement period with AC usage, and differences in the measured temperature were often due to humidity in the indoor air [37]. The highest temperatures were recorded during sunny days in the afternoon. This occurrence proves that the outdoor climate is related to the factors of change in indoor thermal conditions [50], as the indoor temperature was strongly correlated with outdoor temperature during warm outdoor conditions [51,52]. The results showed that the highest measured T_a difference was 2–3 °C, based on setpoint temperatures of 16 and 20 °C. The results for setpoints of 24 and 28 °C showed lower readings for measured indoor temperature. This phenomenon demonstrates that AC users underestimated the higher setpoints and the indoor thermal environment. The acceptable indoor conditions were correlated with the outdoor temperature, which was beneficial to assess the building's performance and specifications [53].

Table 5. Descriptive statistics of indoor environmental parameters.

Students' Activity Rooms	T_s (°C)	Var.	T_a (°C)	Tg (°C)	$Tmrt$ (°C)	Top (°C)	RH (%)	AH (g/kg DA)	V_a (m/s)
A_1 (n = 172)	16	Mean	19.0	19.7	20.6	19.7	53	8.8	0.15
		S.D.	1.2	1.2	1.4	1.2	3	0.5	0.01
	20	Mean	20.4	21.3	22.5	21.2	53	9.6	0.16
		S.D.	1.2	1.3	2.0	1.2	5	0.6	0.02
	24	Mean	23	23.5	24.2	23.5	54	11.4	0.17
		S.D.	0.3	0.4	0.7	0.3	4	0.8	0.01
	28	Mean	26.4	26.6	29.4	26.6	65	16.8	0.16
		S.D.	0.9	0.9	2.3	0.9	5	0.8	0.01
A_2 (n = 80)	16	Mean	18.2	18.7	19.4	18.7	61	9.6	0.14
		S.D.	0.9	1.0	1.4	1.05	4	0.7	0.01
	20	Mean	20.9	21.0	21.5	21.1	66	12.2	0.70
		S.D.	0.6	0.7	2.9	1.1	4	0.9	0.01
	24	Mean	23.5	23.7	23.9	23.7	77	16.7	0.15
		S.D.	0.6	0.7	0.9	0.7	2	0.5	0.02
	28	Mean	26.7	26.7	26.6	26.7	84	22.1	0.38
		S.D.	0.6	0.6	0.6	0.6	2	0.9	0.22

Note: A_1: student activity room 1, A_2: student activity room 2, n: number of samples, Var.: variables, *S.D.*: standard deviation, T_s: setpoint temperature, T_a: indoor air temperature, T_g: indoor globe temperature, T_{mrt}: indoor mean radiant temperature, T_{op}: indoor operative temperature, AH: absolute humidity, V_a: air movement.

4.3. Thermal Responses

Each setpoint temperature distinctly influenced the operative temperatures. The correlation between setpoint temperatures and the operative temperature was determined by regression analysis between the outcomes of the dependent variables of both rooms, as shown in Figure 4. A study by Han et al. [54] also found that different indoor operative temperatures on each day, signified by the same setpoint temperatures, were reflected by daily weather conditions. An acceptable range of setpoint temperatures would optimize building energy consumption, as well as occupants' comfort, and well-being. Hence, the setpoint should not be mistaken as being used only for reference, as its value is defended by operational regulations of air-conditioner systems [55]. In this study, the setpoint temperatures were statistically significantly related to the operative temperatures ($p < 0.001$), as presented in Table 6.

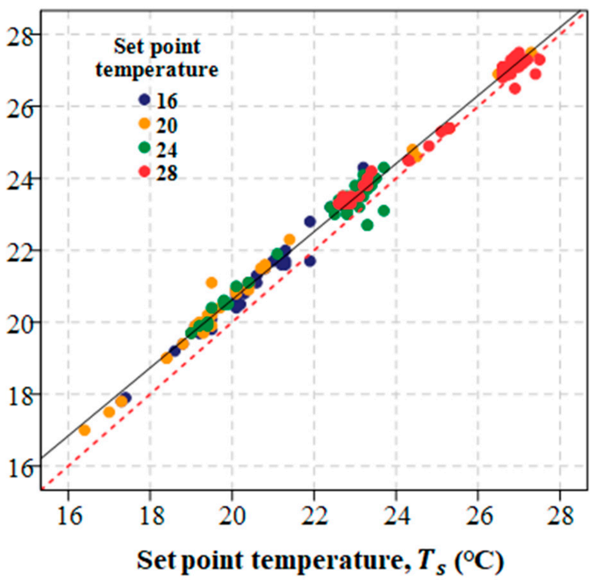

Figure 4. Correlation of indoor operative temperatures with different setpoint temperatures for both student activity rooms.

Table 6. Regression between setpoint temperature and indoor air temperature.

Students' Activity Rooms	*n*	Regression Equation	R^2	*S.E.*
A_1	172	$T_{op} = 0.95T_s + 1.70$	0.99	0.013
A_2	80	$T_{op} = 0.93T_s + 1.76$	0.96	0.024
Both	252	$T_{op} = 0.94T_s + 1.64$	0.98	0.013

Note: A_1: student activity room 1, A_2: student activity room 2, n: number of samples, T_s: setpoint temperature, T_{op}: indoor operative temperature, R^2: coefficient of determination, *S.E.*: standard error of regression coefficient. All correlation coefficients are significant ($p < 0.001$).

4.3.1. Relationships between Variables in Thermal Comfort Parameters

The chi-squared test was carried out to determine the influence of individual characteristics—namely, gender, body mass index, water intake, and clothing insulation—on thermal comfort parameters. For gender differences, the mean *TSV* scores assigned by male and female respondents were almost identical, at values of −1.04 and −1.05, respectively. A study by Karjalainen [56] found no significant differences in neutral temperatures between the genders. Therefore, this factor can generally be considered insignificant with respect to thermal sensation for male and female respondents. However, the results obtained for the other thermal parameters—thermal preference, humidity sensation, humidity preference, air movement, and overall comfort—were statistically significant ($p < 0.05$). This indicates that the gender difference affected other thermal parameters.

There is a need for a comprehensive study to grasp the influence of body mass index (*BMI*) on thermal comfort [57], since the previous studies were aggregate models designed for small sample sizes. The results revealed that the observed frequencies were statistically insignificant, except for the air movement, which had a significant effect ($p < 0.05$) on respondents. Thus, the overall observed frequencies failed to reflect the independence of the respondents' body mass index, as in previous studies conducted by Aleksandra [57]; no statistically significant differences were observed in thermal parameter requirements due to body mass index.

The respondents' water intake was measured by observing the reduction in water content by subtracting the initial water content from the remaining water in the bottle. Generally, people will drink water when they feel uncomfortable in any circumstances—for instance, to stay hydrated; to avoid fatigue; to remedy dry eyes, mouth, and skin; or to maintain body temperature. Greenleaf suggested that the water intake of respondents increases at an ambient temperature of about 27 °C—the temperature at which sweating begins [58]. However, there is inadequate information on the amount of water intake that will generally affect hydration [59]. The results of the chi-squared test showed that respondents' thermal sensation and overall comfort were statistically significant ($p < 0.05$) and strongly correlated with water intake. In contrast, the other thermal parameters were statistically insignificant and independent of the respondents' water intake. The comparison of the average water intake data at four different setpoint temperatures, as indicated with error bars, is presented in Figure 5.

Effective practical clothing adjustments help to maintain thermal comfort in indoor environments, as clothing protects the body against the climatic influence and assists its thermal control functions under various environmental conditions and physical activities, enabling occupants to stay thermally comfortable [60]. The *p*-value for respondents' overall comfort was statistically significant, indicating that their clothing affected their thermal parameters.

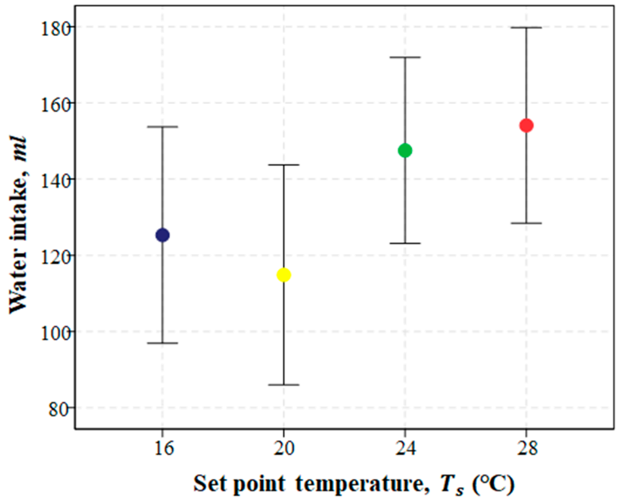

Figure 5. Water intake of respondents at four different setpoint temperatures, with 95% confidence intervals.

4.3.2. Mean Thermal Sensation and Preference Votes

A strong correlation between the mean value of thermal sensation and the mean preference vote was obtained, as shown in Figure 6. The mean value of thermal sensation was between −1.7 and −2.5 for the setpoint temperatures of 16 and 20 °C, respectively. Concurrently, at the setpoint temperature of 24 °C, 41% of the respondents voted '0 neutral' for thermal sensation, while 54% preferred '0 no change'. The highest percentage of preference votes obtained revealed that most respondents felt almost neutral at most of the seating locations in both rooms; 38% voted '1 warm' for thermal sensation, with a mean value between 0.53 and 1.5, which lies in '0 neutral', '1 slightly warm', and '2 warm' on the thermal sensation scale. The mean value of the thermal preference vote was between 0.6 and 1.8, with preferences of '1 a bit cooler' and '2 much cooler', respectively, at most of the seating locations in the rooms. This may be the natural preference of most people living in hot climates for cooler conditions, albeit the people could possibly have accepted any prevailing conditions [61].

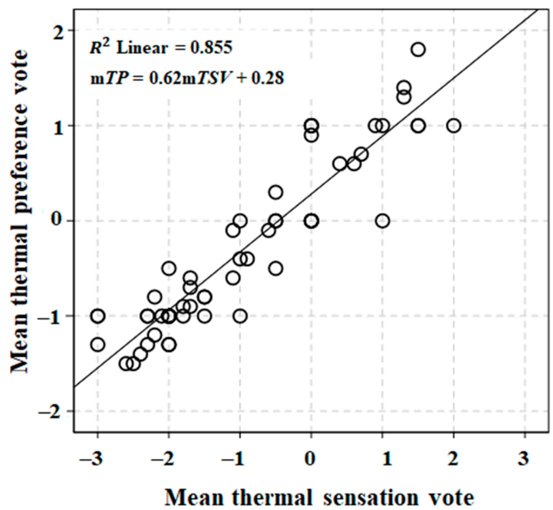

Figure 6. Correlation of thermal preference votes with thermal sensation votes at various indoor operative temperatures for both student activity rooms.

4.4. Comfort Temperatures

4.4.1. Griffiths' Method

Griffiths' method can be applied to determine the indoor comfort temperature of respondents in small-scale samples [62]. In this case study, a Griffiths constant of 0.50

was derived from previous studies [40,63,64] in hot and humid conditions. The comfort temperature was determined from Equation (1), where T is the temperature, '0' is a neutral condition, and α is the Griffiths constant or regression coefficient [65]. Table 7 presents the mean comfort temperature determined by applying Griffiths' method, with votes of '0 neutral' for TSV and overall comfort votes of '5 moderately comfortable' and '6 very comfortable'. Overall, based on our findings from the comparison of Griffiths' method with the thermal sensation vote and overall comfort, it was discovered that the mean indoor operative comfort temperature was 24.3 °C.

$$T_c = T + \frac{(0 - TSV)}{\alpha} \quad (1)$$

The thermal sensation votes of '0 neutral' were found at a mean comfort temperature of 24.9 °C, with a 0.6 °C difference from the results estimated by Griffiths' method. In contrast, the mean comfort temperature obtained from the overall comfort, with votes of either '5 moderately comfortable' or '6 very comfortable', was slightly lower, at 22.9 °C.

Table 7. Griffiths comfort temperatures and mean operative temperatures with votes.

Students' Activity Room	Griffiths' Method			TSV = 0			OC = 5 or 6		
	n	T_{cop} (°C)	S.D.	n	T_{cop} (°C)	S.D.	n	T_{cop} (°C)	S.D.
A_1	172	25.1	1.8	32	25.1	1.6	63	23.4	2.4
A_2	80	24.4	1.5	16	24.6	1.5	19	21.7	2.3
Both	252	24.3	2.6	48	24.9	1.6	82	22.9	2.7

Note: A_1: student activity room 1, A_2: student activity room 2, n: number of samples, TSV: thermal sensation vote, OC: overall comfort, T_{cop}: mean operative comfort temperature, *S.D.*: standard deviation.

4.4.2. Comparison of Comfort Temperatures from Field Studies of AC Modes

The thermal comfort temperature is defined as human comfort under a given room condition, even if there are differences in individual perceptions or sensations. The results were compared to those of a previous study based on the mean indoor comfort temperature estimated by Griffiths' method for residential buildings, as presented in Table 8, with various temperature settings.

Table 8. Comparison of comfort temperatures for residential buildings with AC modes.

Author	Country	Setpoint Temperature, T_s (°C)	Comfort Temperature, T_c (°C)
This study	Malaysia	16, 20, 24 and 28	24.3
Uno et al. [11]	Indonesia	18 to 26	25 to 27
Karyono [66]	Indonesia	-	T_{ca} = 25.7 T_{cg} = 25.4
Karyono et al. [67]	Indonesia	-	T_{ca} = 22.6 to 25.7 T_{cg} = 19.6 to 23.9
Mishra & Ramgopal [68]	India	-	22.1 to 31.5
Rangsiraksa [69]	Thailand	-	25
Puangmalee et al. [18]	Thailand	25 to 28	28
Sudprasert [63]	Thailand	-	29
Zhang et al. [70]	China	26	20.6 to 30.5
Li et al. [27]	China	21 to 27	26 to 28
Honjo et al. [71]	Japan	-	26.1
Budiawan and Tsuzuki [72]	Japan	-	28.1
Hwang and Chen [73]	Taiwan	-	23.2 to 27.1
Rajasekar and Ramachandraiah [74]	India	-	26.8 to 31
Indraganti [75]	India	-	26.0 to 32.5
De Vecchi et al. [76]	Brazil	21 to 24	22.5

4.4.3. Thermal Comfort Zone

Probit regression was used for analysis to estimate respondents' thermal comfort zone [77], with the acceptable comfort limit based on TSV results [78]. The thermal comfort zones of respondents can be estimated by analyzing the data using probit regression. Each probit equation was calculated using a function (Equation (2)) [37,61,76] representing the lines between the proportion of *TSV* and the six lines encompassed within the area of seven-point scale votes [79]. Figure 7 shows the curve of the proportional area. The mean indoor operative temperature of each probit equation was estimated by dividing the constant value by the regression coefficient, where *CDF.NORMAL* is the cumulative distribution function for the normal distribution, 'quant' is the indoor air temperature (°C), and the 'mean' and '*S.D.*' are given in Table 9.

$$\text{Probability} = \text{CDF.NORMAL}(\text{quant}, \text{mean}, S.D.) \quad (2)$$

The proportional area of each seven-point scale comfort vote was divided by the curves, as shown in Figure 7a. The top line describes the proportional area of *TSV* '−3 very cold', followed by the second line, which is defined as the proportional area of *TSV* '−2 cold', and so on, until the bottom line of *TSV* '3 hot'. The optimal proportion of indoor thermal comfort was 58% for respondents who voted either −1, 0, or 1, and it was statistically significant ($p < 0.001$), indicating that the respondents were thermally comfortable within 24–26 °C in the student activity rooms.

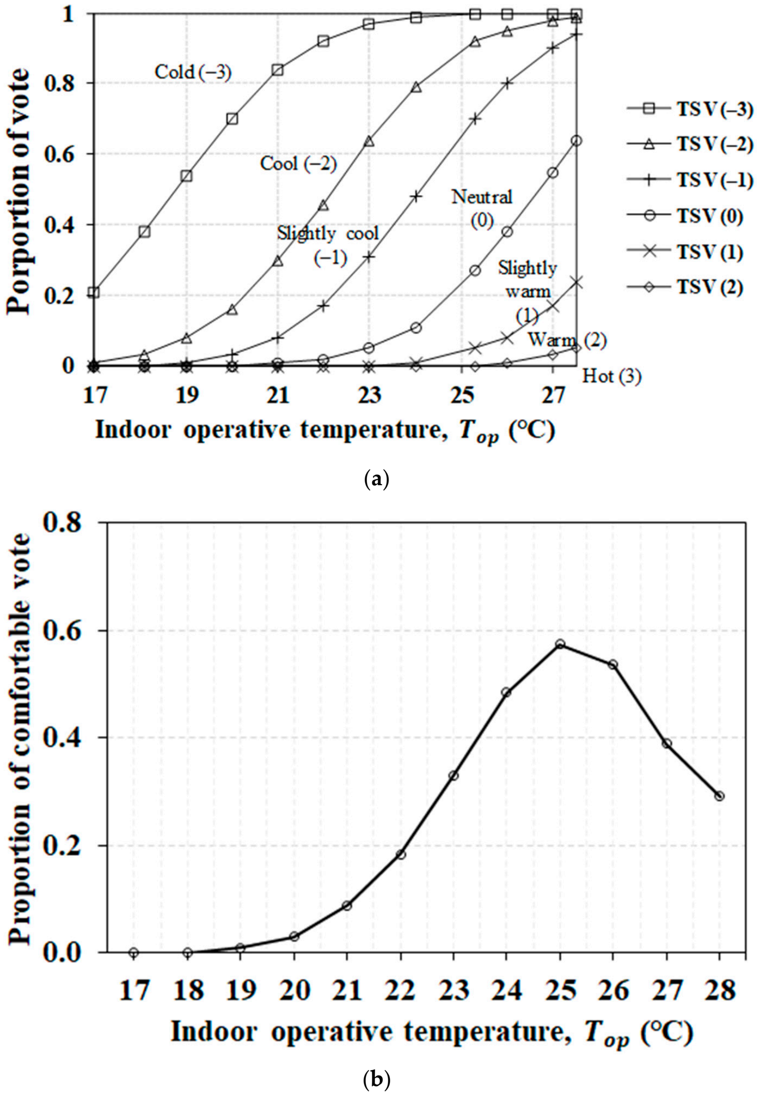

Figure 7. Proportion of *TSV* with significant probit results: (**a**) each proportion of votes and (**b**) proportion of comfortable votes for both student activity rooms.

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

Probit Equation	Mean (°C)	*S.D.*	R^2	*S.E.*
P (≤−3) = 0.45T_{op} + 8.38	18.8	0.033	0.58	0.033
P (≤−2) = 0.45T_{op} + 9.87	22.2			
P (≤−1) = 0.45T_{op} + 10.72	24.1			
P (≤0) = 0.45T_{op} + 11.89	26.7			
P (≤1) = 0.45T_{op} + 12.95	29.1			
P (≤2) = 0.45T_{op} + 13.87	30.5			

Note: P (≤−3) is the probit of the proportion of the votes that are −3 and less, P (≤−2) is the probit of the proportion that are −2 and less, and so on; *S.D.*: standard deviation, *N*: number of samples, R^2: cox–Snell coefficient of determination, *S.E.*: standard error. Probit equation is based on significant regression coefficients. All correlation coefficients are significant ($p < 0.001$).

The results were compared to those of a previous study based on mean indoor temperature estimated by probit analysis for residential buildings, as presented in Table 10. The comparison was made based on location in a hot and humid climate or studies conducted during the summer season in specific areas.

Table 10. Comparison of comfort temperatures of previous studies.

Location	Reference(s)	*N*	Observed T_c (°C)
Malaysia	This study	252	25.0
China	Hwang and Chen [73]	1955	24.2
Japan	Rijal [43]	3991	26.0
Thailand	Aryal et al. [80]	300	26.3
Japan	Rijal et al. [81]	6872	25.0

Note: *n*: number of samples, T_c: comfort temperature.

4.4.4. Predicted Mean Vote and Percentage of Dissatisfied

Predicted mean vote (*PMV*), developed to predict thermal sensation for humans as an empirical index, refers to the average of the group of people on the ASHRAE [47] thermal sensation scale. The parameters measured to estimate the *PMV* index included air temperature, mean radiant temperature, relative humidity, clothing insulation, and metabolic rate, to predict thermal comfort. The predicted percentage of dissatisfied (*PPD*) index was derived from the *PMV* index to determine the percentage of people experiencing thermal discomfort or dissatisfaction. People may feel either too hot or too cold in each thermal environment [82]. Therefore, it depends on the thermal climatic conditions, which could present values of *PMV* exceeding the range of $-3 \le TSV \le 3$ [83]. The actual percentage of dissatisfied (*APD*) was estimated by replacing the *PMV* index with the *TSV* index. The overall results of the *PMV* and *PPD* indices obtained, in comparison to *TSV* and *APD*, are shown in Table 11.

Table 11. *PMV* and *TSV* results.

Variables (n = 252)	*PMV*	*PPD* (%)	*TSV*	*APD* (%)
Mean	1.5	36	1.4	35
S.D.	−2.2	67	−1.0	51

Note: Min.: minimum, Max.: maximum, *S.D.*: standard deviation, *PMV*: predicted mean vote, *PPD*: predicted of percentage dissatisfied, *TSV*: thermal sensation vote, *APD*: actual percentage of dissatisfied.

4.5. Development of Adaptive Models in AC Spaces

4.5.1. Running Mean Outdoor Temperature

The international standards of Environmental Design Guide A of the Chartered Institution of Building Services Engineers (CIBSE) were mainly designed for AC spaces. However, there are no standards explicitly for residential buildings; thus, the mentioned standards and guidelines were considered as a reference to verify the research conducted on the acceptability of indoor environments. The data were plotted according to Equation (3) from the CIBSE guidelines [35], with upper and lower limits of ±2 K, where the operative comfort temperatures were plotted against the running mean temperatures as presented in Figure 8. Running mean daily outdoor air temperature (T_{rm}) refers to the mean outdoor air temperature across seven consecutive days, depending on the day on which the field study was conducted. The T_{rm} was calculated based on the recorded outside air temperature by using Equation (4) [35,75,76,79,84]:

$$T_c = 0.09T_{rm} + 22.6 \quad (3)$$

$$T_{rm} = \alpha T_{rm-1} + (1 - \alpha)T_{od-1} \quad (4)$$

where T_{rm} is the running mean outdoor temperature for the previous day (°C), and T_{od-1} is the daily mean outdoor temperature for the previous day (°C). Moreover, whenever the running mean has been calculated for one day, it can be readily calculated for the next day, and α is a constant assumed to be 0.8 [53,62,85,86].

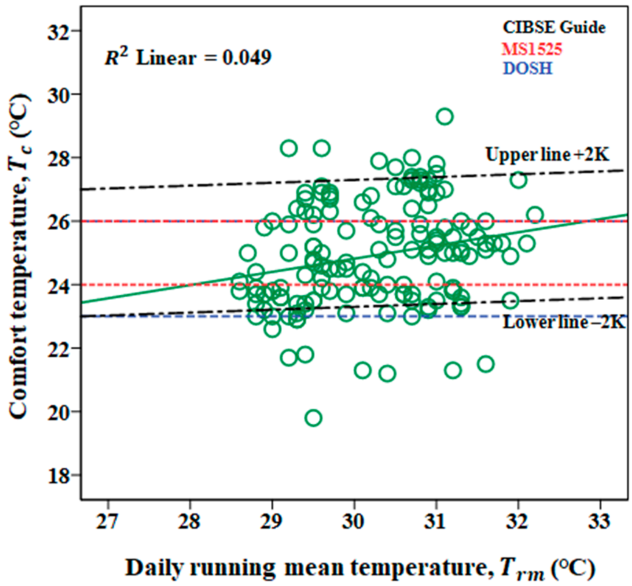

Figure 8. Comparison of predicted comfort temperatures with relevant standards.

The indoor comfort temperatures of respondents were found to be both inside and outside of the CIBSE, within 23–25 °C. The results were compared to MS1525, with a comfort zone between 24 and 26 °C, and the Department of Occupational Safety and Health (DOSH), with a comfort zone between 23 and 26 °C. Overall, the comfort temperatures were found to be within the range of the thermal comfort zone, excluding almost 40% who felt comfortable at low setpoint temperatures, as mentioned by Hoof and Hensen [87] and Schellen et al. [88], who noted that young adults might have a high preference for lower temperatures. Generally, there is no international adaptive standard for comfort temperature in AC buildings, as the infiltration of outdoor air into such buildings is assumed to be minimal [61]. However, there is still a correlation between outdoor and indoor air temperatures in AC buildings [49].

4.5.2. Adaptive Thermal Comfort Model

The adaptive model to predict comfort temperature is associated with climate. Outdoor climate may influence indoor thermal comfort [49,89], with the ability of humans to adapt to the environment. Naturally, humans will exhibit behavioral, physiological, and psychological reactions if they feel discomfort due to the thermal environment; concurrently, the thermal sensation can be expressed [49,90,91]. Thus, the results obtained from this study were compared to the regression equation of the comfort temperature to the running mean outdoor temperature in hot and humid climates, derived from previous studies on cooling modes, as shown in Table 12. The regression coefficient was higher than the CIBSE guideline for cooling and heating modes, at 0.09. The significant difference in the indoor temperature in the rooms reflects the high gradient for the adaptive model used in this study. The equation can predict the indoor comfort temperature for these buildings.

Table 12. Regression equations for cooling modes used in previous studies.

References	Buildings	Regression Equation	*n*	R^2	*S.E.*
This study	University	T_c = 0.42 T_{rm} + 12.3	252	0.049	0.006
Karyono [67]	University	T_c = 0.75 T_{rm} + 5.95	72	0.38	-
Honjo et al. [71]	Residential	T_c = 0.29 T_{rm} + 18.8	1955	0.03	-
Rijal et al. [92]	Residential	T_c = 0.18 T_{rm} + 22.1	2109	0.10	0.013
CIBSE [35]	Offices	T_c = 0.09 T_{rm} ± 22.6	-	-	-
Rijal et al. [93]	Offices	T_c = 0.065 T_{rm} + 23.9	4857	0.08	0.005
Rijal et al. [94]	Offices	T_c = 0.359 T_{rm} − 8.5	1241	0.37	0.024
Indraganti et al. [95]	Offices	T_c = 0.15 T_{rm} + 22.1	4310	0.026	0.014

Note: T_c: comfort temperature (°C), T_{rm}: daily running mean outdoor temperature (°C), *n:* number of samples, R^2: coefficient of determination, *S.E.:* standard error of regression coefficient.

4.5.3. Indoor Environmental Conditions and Applicability of Standards

The results obtained from indoor thermal environment parameters such as temperature and humidity in the two student activity rooms were compared to the acceptable ranges set out by related standards. Hence, the data collected for various indoor air temperatures are presented in a psychrometric chart to assess the suitability of applying ASHRAE Standard 55 [47], as shown in Figure 9.

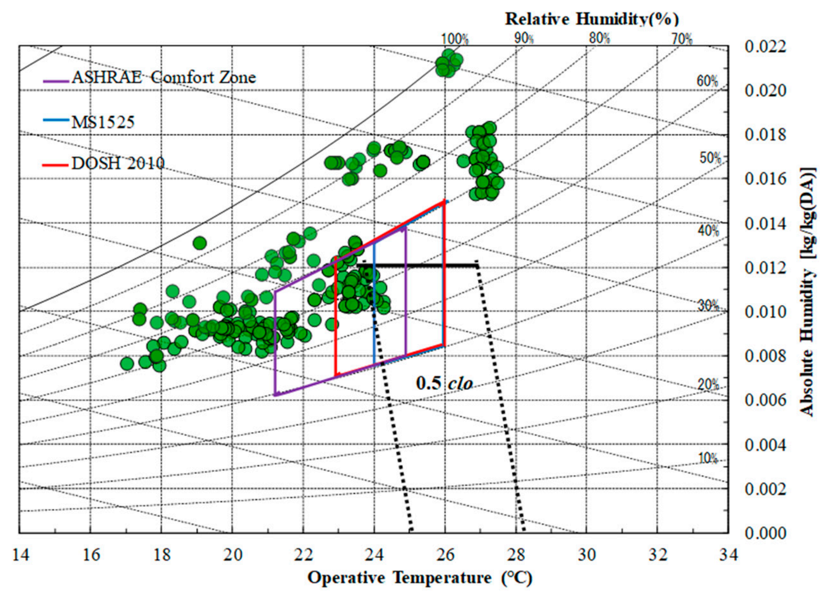

Figure 9. Distribution of indoor thermal environment measurements on the ASHRAE Standard 55-2017 comfort chart; dashed lines represent summer clothing zones and solid lines represent humidity guidelines.

The measurement results showed that about 32% and 44% of the data were above the respective humidity guidelines. The maximum humidity ratio value was 0.012 kg/kg(DA) of indoor temperature, and humidity data were plotted on the psychrometric chart in ASHRAE Standard 55. According to ASHRAE [96], the acceptable ranges are 21–24 °C and a maximum of 60% *RH*, while based on the local standards, the acceptable air temperature ranges for AC spaces are 24–26 °C and 50–70% *RH*, and 23–26 °C and 40–70%

RH, respectively. From the measured data, it was found that 29% of data fell within the ASHRAE and DOSH guidelines. These findings were consistent with those of previous studies on residential buildings in hot and humid climates or summer seasons, as presented in Table 13.

Table 13. Comparison of indoor environmental conditions for residential buildings in a hot and humid climate or summer season.

References	n	T_a (°C)	RH (%)	Absolute Humidity, AH (g/kg. DA)
This study	252	17.0 to 27.5	50 to 98	8 to 22
Imagawa and Rijal [97]	1176	26.3 to 27.9	38 to 78	-
He et al. [98]	467	21.0 to 29.3	46 to 91	-
Kong et al. [99]	24	25.0 to 28.0	20 to 90	-
Budiawan and Tsuzuki [72]	18	24.6 to 29.0	55 to 79	12.9 to 21.5
Zaki et al. [100]	20	23.0 to 24.7	68 to 74	12.5 to 14.8
Aryal et al. [80]	300	24.9 to 26.7	37 to 98	-

Note: n: number of samples, T_a: air temperature, RH: relative humidity, AH: absolute humidity.

5. Study Limitations

This study's limitations arise from using setpoint temperatures as reference temperatures. At the same time, the measured readings were inconsistent with indoor air temperature relative to the varied outdoor conditions. Moreover, outdoor conditions tended to deviate between the datasets, as the measurements were conducted at different times and days. The study was conducted in student activity rooms with students in a relaxed mode, engaging in only light physical activities, to represent the human conditions in a living room area.

6. Conclusions

This study investigated thermal adaptation under AC setpoint temperatures of 16, 20, 24, and 28 °C in student activity rooms in a university building in Malaysia. The key findings from this study for the first objective, based on chi-squared results, revealed that body mass index and water intake did not affect the thermal comfort parameters (i.e., thermal preference, humidity sensation and preference, and air movement vote). Water intake had a significant effect on overall comfort. Moreover, gender and body mass index had no significant effects on the thermal sensation of respondents. In contrast, water intake and clothing insulation levels significantly affected personal thermal comfort. Then, the comfort temperature of the respondents was found to be 24.3 °C—within the thermal comfort zone recommended for commercial buildings, with a minimum setpoint of 24 °C based on the guidelines of Malaysian standards. The finding indicates that comfort temperature and preference are associated with the gap in occupants' preferences in hot and humid climates for indoor thermal comfort. The survey supported this, revealing that 41% of respondents felt comfortable at lower indoor temperatures.

The adaptive model for the third objective was proposed to estimate and control indoor comfort temperature based on the relationship between indoor and outdoor conditions. This model can be applied for thermal simulation to estimate comfort temperature in buildings with a similar climate. Lastly, about 29% of data fell within the ASHRAE and DOSH guidelines for AC spaces. About 45%, 38%, and 40% were within the ASHRAE, DOSH, and MS1525 comfort zones, respectively, with 25% below the setpoint of 24 °C. Hence, the findings of the present study indicate that a minimum setpoint temperature of 24 °C could be implemented to promote energy-saving behavior without neglecting the occupants' comfort, as agreed by Malaysian standards.

The suitability of the proper thermostat setting for mechanical cooling devices directly affects indoor cooling satisfaction. The appropriate guidelines and information on the manner of AC usage can be extended by educating the occupants on the importance of practicing better use behaviors to mitigate the impact on the environment in the long run.

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Appendix A

Sample of a survey based on the scale for thermal comfort questionnaire in a student activity room

Thermal sensation, acceptability, preference, and comfort

1. How do you feel about your current health condition?

Good	4	
Fair	3	
Bad	2	
Very Bad	1	

2. How do you feel about the hotness and coldness in room right now?

Very Cold	−3	
Cold	−2	
Slightly Cold	−1	
Neutral	0	
Slightly warm	1	
Warm	2	
Very hot	3	

3. How do you prefer temperature now?

Much warmer	−2	
A bit warmer	−1	
No change	0	
A bit cooler	1	
Much cooler	2	

4. Is the air movement acceptable?

No	
Yes	

5. How do you feel the air humidity right now?

Very dry	−3	
Dry	−2	
Slightly Dry	−1	
Neutral	0	
Slightly humid	1	
Humid	2	
Very humid	3	

6. How do you prefer the air humidity right now?

Much more humid	−2	
A bit more humid	−1	
No change	0	
A bit drier	1	
Much drier	2	

7. How do you feel the air movement right now?

Very bad	−3	
Bad	−2	
Slightly Bad	−1	
Neither bad nor good	0	
Slightly good	1	
Good	2	
Very Good	3	

8. How would you rate your overall comfort, by considering the condition right now?

Very comfortable	6	
Moderately comfortable	5	
Slightly comfortable	4	
Slightly uncomfortable	3	
Moderately uncomfortable	2	
Very uncomfortable	1	

9. How do you spend up to 15 min before now? (Please select one main activity).

Using smartphone	
Typing notes/assignment using PC	
Surfing the internet using PC	
Watching movies/dramas	
Reading books/magazines etc.	
Chatting	
Seated, quiet	

Adaptive methods

1. What kind of action did you take to stay comfort in a current temperature setting? Please choose the applicable items.

I drink a water bottle provided	
I roll up the shirt's sleeve or pants	
I rubbed both palms	
I'm fanning myself using paper/thin book	
I did nothing	
Other (please write)	

Clothing Insulation

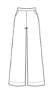
1. Please tick (√) on the following list, for the clothing items that you are wearing now.

Male:

Inner	Men's brief 	
	Sleeveless shirt 	
	Thin pants 	
Shirt	Sport shirt 	
	T-shirt 	
	Long sleeve shirt 	
Bottom	Shorts 	
	Light trousers 	

Female:

Inner	Bra & panty 	
	Sleeveless shirt 	

Shirt	Sport shirt 	
	T-shirt 	
	Long sleeve shirt 	
Bottom	Shorts 	
	Long skirt 	
	Thin long trousers 	
	One-piece dress 	

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