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Case Report

Investigating adaptive thermal comfort in office settings: A case study in Johor Bahru, Malaysia

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ABSTRACT

This study investigates the notion of adaptive thermal comfort in office settings situated in the tropical climate of Johor Bahru, Malaysia. The primary objective of this study is to examine the impact of regulated office attire and different types of spaces equipped with varying ventilation systems on individuals' perception and adjustment to thermal comfort. Data was collected through various research methods, including quantitative and qualitative techniques, as well as surveys, observations, and tangible measurements. The study's results highlight the significance of clothing insulation in achieving optimal thermal comfort. Individuals who could adjust the insulation of their clothing within a range that was deemed comfortable expressed greater satisfaction. Additionally, it has been found that semi-outdoor environments featuring natural ventilation provide a wider range of comfortable temperatures compared to indoor spaces equipped with air conditioning. This suggests the possibility of designing public areas prioritizing natural ventilation to enhance comfort and promote sustainability. Furthermore, this study delineates potential avenues for future research within the context of Malaysia and the climatic conditions prevalent in tropical regions. It is worth noting that there is a recommendation to research the influence of air velocity on thermo perception and adaptation, as previous studies have indicated its significant effect on the perception of comfort. Furthermore, it is crucial to prioritize calculations and simulations of energy consumption to assess the potential for energy savings through adaptive thermal comfort strategies in the specific local context. This will aid in the advancement of sustainable and energy-efficient design strategies. The findings above enhance the understanding of adaptive thermal comfort in Malaysia and offer valuable insights for optimizing workspace design and management. Enhancing productivity, well-being, and energy efficiency in office buildings can be achieved by addressing the thermal comfort requirements of office workers. The findings and recommendations of this study have the potential to provide valuable assistance to policymakers, architects, and facility managers in the establishment of office environments that are healthier, more comfortable, and more energy-efficient within the context of Malaysia's tropical climate.

1. Introduction

In developing nations like Malaysia, employers frequently establish uniform or formal dress codes that regulate the appearance of their personnel, including students and officials of state-owned organizations [1]. Similar rules about clothes are in effect in private businesses to keep a professional image [2]. These standards, however, frequently ignore how employees' wardrobe choices affect their thermal comfort and perception in the workplace [3]. The ability to adjust and adapt to one's thermal environment is made possible by clothing, which significantly impacts human thermal comfort in any given situation [4]. The climate of a given place has been found to impact insulation and clothing choices [5]. Nevertheless, more research needs to be done on how socio-cultural and climatic aspects affect people's clothes choices at work and their thermal comfort. The Japanese Cool Biz Campaign, run by the Japanese Ministry of Environment in 2005 [6], illustrates the importance of clothes in a person's thermal comfort. Government employees were expected to follow a dress code during this campaign, including wearing short-sleeved shirts without ties or coats and breathable and moisture-absorbent pants [7]. The campaign's goal was to minimize energy consumption by limiting air conditioning use. As a result, all central government departments implemented air conditioning temperatures of 28 °C until the end of the summer. A comparable initiative known as Super Cool Biz was launched in the summer of 2012 in reaction to the Great East Japan Earthquake of March 11, 2011 [8].

The acceptable comfort temperature range for office workers in various cities and building types was examined in great detail in the literature review undertaken for this study. Both non-air-conditioned (NV) homes and air-conditioned (AC) offices were the focus of studies conducted in Singapore in 1991 by de Dear et al. who reported neutral temperatures of 28.5 °C and 24.2 °C, respectively [9]. Another study at air-conditioned offices in Singapore discovered that the ideal

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temperature range for them was between 23.6 and 26.4 °C, with 24.8 °C being the neutral temperature [10]. Further research on thermal comfort in Singapore's NV dwellings revealed neutral temperatures of 29.3 °C or 28.6 °C and a satisfaction range of 25.1 °C–28 °C [11]. Neutral temperatures were reported to be 29.6 °C and 26.8 °C by researchers who studied NV and AC office environments in China [12]. Busch's studies in Bangkok in 1992 looked at both AC and NV office areas, and they found that the neutral temperatures were 24.7 °C and 27.4 °C, respectively, with acceptable temperature ranges of 22 °C–28 °C and up to 31 °C [13]. Thermal comfort in AC and NV classrooms was investigated in Hawaii, where neutral temperatures of 26.8 °C and 27.4 °C were noted [14]. Researchers from Taiwan who concentrated on NV + AC classrooms reported a neutral temperature of 26.3 °C with an acceptable range of 21.1 °C–29.8 °C [15]. Another study looked into NV + AC office spaces in Jakarta and found that the acceptable temperature range was 23.5 °C–29.9 °C, with 26.7 °C being the neutral temperature [16]. Further research on thermal comfort in Jakarta, NV households revealed neutral temperatures of 29.2 °C or 29.9 °C [18]. NV houses in Hyderabad were the subject of a study that determined a neutral temperature of 29.2 °C and an acceptable range of 26.0 °C–32.5 °C [18]. Researchers in Guangzhou looked at NV schools and homes, highlighting acceptable temperature ranges of up to 29.5 °C or 31.0 °C [19]. Last but not least, NV studios and classrooms were the subjects of a study in Maceio, which reported temperature acceptability related to external temperature, with a maximum of 32 °C [20]. These studies help design suitable semi-outdoor and indoor spaces and enhance occupant satisfaction and productivity by offering useful insights into the appropriate comfort temperature range for office workers in various cities and building types.

The main goal of this paper is to evaluate how well office workers can adjust to the thermal circumstances in a tropical climate in the presence of uniform or clothing regulations. The study was carried out in Johor Bahru, a state in southern Malaysia, emphasizing various levels of the UTHM library. A strict official uniform policy was followed on one floor, but there was no dress code on the floor next to it. The research intends to shed light on the impact of office dress policies on thermal comfort and adaptation by closely watching and analyzing the thermal experiences of office workers in these various situations. Through this work, important understandings can be achieved about the connection between required professional attire and the success of thermal adaptation in a tropical environment.

The remainder of this paper is structured as follows: Section 2 provides an overview of the studied location, Section 3 offers a concise explanation of the subjective measurement methodology, and Section 4 presents the details of the physical measurements conducted. Section 5 is dedicated to presenting the results and discussions, and the paper concludes with a summary in the final section.

2. The studied location

The field research was conducted in Johor Bahru, a southern state in Malaysia. The study focused on the library building of Universiti Tun Hussein Onn Malaysia (UTHM), situated approximately 20 km from Batu Pahat city. The building features a circular geometrical design with a central courtyard. It encompasses five levels, including multipurpose rooms, a computer room, a bookstore, a small canteen on the ground level, library spaces on levels one to four, and an administration room on the top level. The building spans a total plan area of 8091 m2, with a diameter of 101.5 m. The courtyard occupies 13% of the total area, amounting to 804 m2, with an inner diameter of 36 m. Being isolated from surrounding buildings, the UTHM library enjoys direct wind flow with minimal obstructions. Malaysia falls under the Koppen's climatic classification of "equatorial fully humid," as depicted in Fig. 1.

Malaysia's tropical climate is characterized by two distinct monsoon seasons: the Northwest Monsoon from October to February and the Southwest Monsoon from April to October. The country experiences regular thunderstorms and squalls during these periods. With average annual precipitation reaching 100 inches in West Malaysia and 150 inches in East Malaysia, high humidity levels of 70%–90% are prevalent throughout the year. The average temperature remains relatively constant, ranging from 22.2 °C (72 °F) to 32.2 °C (90 °F). The UTHM library building in Johor Bahru serves as the case study for this research, featuring a circular design with a central courtyard as shown in Fig. 2. The study specifically focuses on the Ground Floor, First Floor, Second Floor, and Third Floor, with varying spaces categorized as semi-outdoor, indoor, and open indoor areas.

The UTHM library cafeteria, located on the ground level and positioned adjacent to the courtyard, featuring a generous ceiling height of 6 m. The cafeteria's side walls are constructed using 110 mm thick brick walls, while the remaining surrounding walls consist of 125 mm thick autoclaved aerated precast concrete. Both wall types are finished with coating and plaster. Spanning an approximate area of 450 m2, the

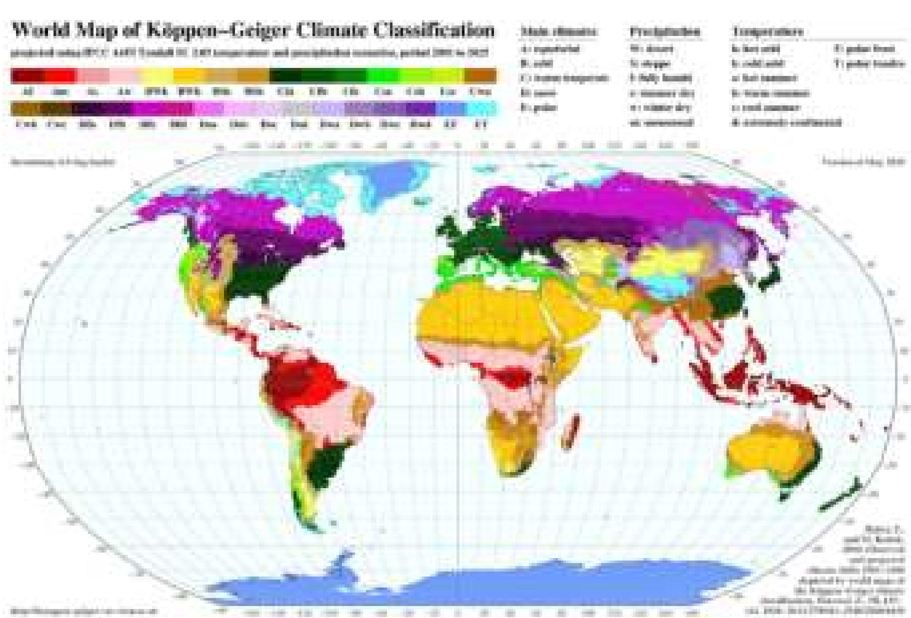

Fig. 1. World Map climate classification.

Fig. 2. UTHM library garden in courtyard spaces (semi-outdoor space).

cafeteria benefits from fan-assisted ventilation through wall-mounted fans. The seminar room, boasting a ceiling height of 3.2 m. The front wall of the room is constructed with 110 mm thick brick wall, while the other surrounding walls feature 125 mm thick autoclaved aerated precast concrete. Similar to the cafeteria, the walls are finished with coating and plaster. The seminar room occupies an area of 400 m2, with openings provided by windows and doors. The total opening size accounts for 10.55 m2. For mechanical ventilation, a centralized air conditioning system is employed in the seminar room and all indoor spaces.

3. Qualitative study

In this study on subjective measurements, a group of participants was recruited from the voluntary pool of UTHM library workers. To collect relevant information about their workspaces, a comprehensive questionnaire was employed. The questionnaire covered various aspects such as gender, age, working hours, and the duration of their residence in Johor Bahru. Additionally, office-related details including typology, ventilation system, number of occupants, presence of external windows, workstation arrangement, and the number of building floors were also collected during the initial phase of the study. To provide an overview of the participants' background, Table 1 presents a summary of their information. The study involved a total of 970 participants, and data were collected during two distinct seasons: from April to October 2022 and from October 2022 to March 2023. The table presents the sample sizes and corresponding percentages for each gender category, age group, and the number of years spent in Malaysia. This background information plays a vital role in understanding the demographic characteristics of the sample, providing valuable insights into the diversity within the study population.

The table reveals several key findings regarding the participants' background information. Firstly, in terms of gender distribution, there were 450 male participants, accounting for 46.4% of the total sample, and 520 female participants, making up 53.6% of the total sample. During both seasons, the proportion of male and female participants remained relatively consistent. Regarding age groups, the majority of participants fell into the 19–24 age range, with 350 individuals representing 36% of the total sample. The next largest age group was 25–30, comprising 335 participants (34.6%). The distribution across age groups remained relatively stable between the two seasons. When considering the duration of participants' stay in Malaysia, the table shows that the largest category was individuals who had been in the country for more than 10 years, with 450 participants (46.4%). The next largest category was individuals who had been in Malaysia for 1–5 years, accounting for 175 participants (18%). The distribution of years spent in Malaysia varied slightly between the two seasons, with a higher proportion of participants staying for longer periods during the April to October 2022 season.

This histogram of Fig. 3 illustrates the distribution of males and females across different office spaces, providing the percentages. The histogram consists of two sets of bars, with blue bars representing males and red bars representing females. The x-axis represents the categories of office spaces, while the y-axis represents the percentage distribution. By examining this histogram, we can identify any gender disparities or preferences in the distribution of individuals among various office space categories. It offers valuable insights into gender composition and distribution patterns within the workplace environment.

This histogram of Fig. 4 visually presents the percentage distribution of males across various age groups in different office spaces. It consists of five distinct categories: "Age-19-24," "Age-25-30," "Age-31-35," "Age-36-40," and "Age>40," each represented by a set of bars with different colors. The x-axis denotes the office space categories, while the y-axis represents the percentage distribution. By examining this histogram, we can easily compare and analyze the distribution patterns of males in different age groups across office spaces. It provides valuable insights into the trends and patterns related to age and office space allocation.

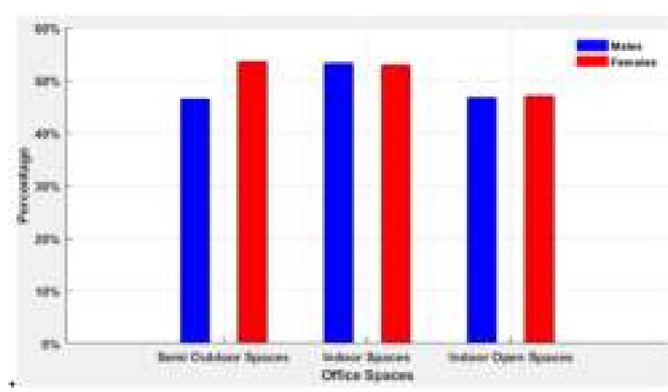

Fig. 3. Grouped Histogram of Percentage (Male vs Female).

Table 1
Summary of participants' background information: Gender, age, and years in Malaysia.

		Total(n = 970)		Season (April to October 2022)		Season (October 2022 to March 2023)	
		Sample size	Percentage	Sample size	Percentage	Sample size	Percentage
Gender	**Male**	450	46.4%	240	53.3%	210	46.7%
	Female	520	53.6%	275	52.9%	245	47.1%
Age years	**19–24**	350	36%	195	55.8%	155	44.2%
	25–30	335	34.6%	180	53.8%	155	46.2%
	31–35	140	14.5%	80	57.2%	60	42.8%
	36–40	100	10.3%	60	60%	40	40%
	>40	45	4.6%	27	60%	18	40%
Years in Malaysia	**< 1**	90	9.3%	50	55.5%	40	44.5%
	1–5	175	18%	95	54.3	80	45.7%
	6–10	130	13.4%	55	42.3%	75	57.7%
	>10	450	46.4%	250	55.5%	200	44.5%
	Missing	125	12.9%	70	56%	55	44%

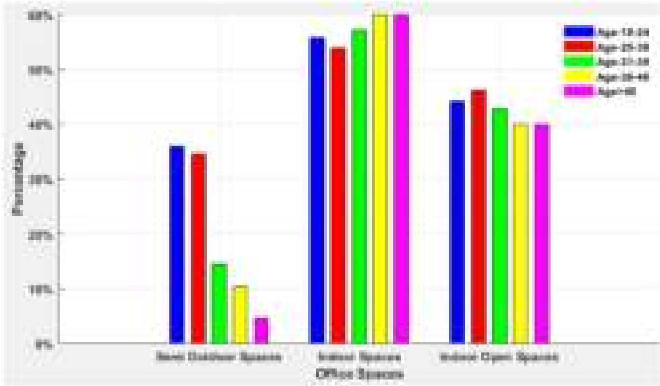

Fig. 4. Grouped Histogram of Percentage (Different ages).

The legend accompanying the histogram offers a clear representation of the color codes corresponding to each age group.

The grouped histogram provides a comprehensive understanding of the variations in the percentage of males across different age groups and office spaces. This analysis is valuable for identifying potential age-related preferences or trends in the selection of office spaces by males. By examining the distribution patterns in the histogram, we can gain insights into the specific age groups that show a higher or lower percentage of male occupants in different office spaces. This information can be instrumental in understanding the factors influencing the choice of office spaces among males based on their age demographics.

The histogram of Fig. 5 illustrates the percentage of males in various office spaces categorized by their duration of stay in Malaysia. The histogram is divided into five categories: "year<1," "year 1–5," "year 6–10," "year>10," and "Missing," each represented by distinct colored bars. The x-axis denotes the office space categories, while the y-axis represents the percentage. This visual representation enables us to observe the distribution patterns of males across different office spaces based on their length of stay. By analyzing the histogram, we can gain insights into how the duration of their stay in Malaysia influences the occupancy of males in various office spaces.

The subjective measurements conducted in this study revealed interesting findings regarding thermal comfort. The average Clo value for respondents in the cafeteria and garden areas was 0.46, while for the seminar room it was 1.05. This indicates a significant difference in thermal insulation influenced by personal clothing adaptations. Specifically, respondents who lectured in the seminar room tended to wear additional jackets compared to those in the semi-outdoor and courtyard garden areas. The metabolic rate value was standardized at 1.22 Met, reflecting a sedentary activity level of sitting with light work.

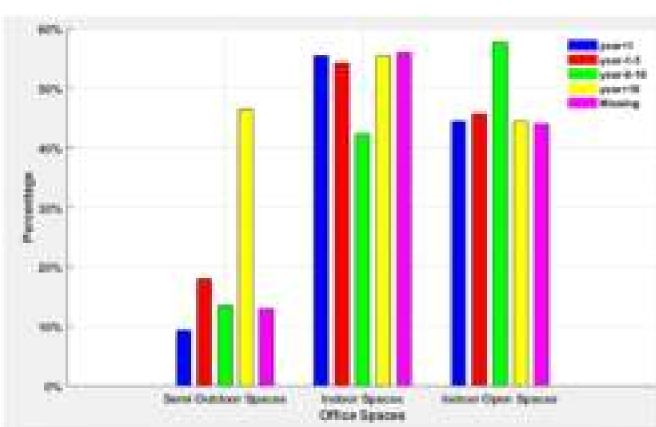

Fig. 5. Grouped histogram of percentage (years in Malaysia).

Table 2 presents the mean Thermal Sensation Vote (TSV) values obtained from the questionnaire. The cafeteria, courtyard garden, and seminar room had TSV values of +0.4, +0.12, and −0.36, respectively. It is worth noting that naturally ventilated spaces showed higher TSV values compared to air-conditioned spaces. However, both TSV values fell within the recommended range of Predicted Mean Vote (PMV) according to the ASHRAE 55 standard ($-0.5 < PMV < +0.5$). These results indicate that, on average, all respondents experienced a thermally comfortable environment.

Table 3 provides a summary of the participants' thermal perception votes across different office spaces.

The table presents the total number of participants, the minimum and maximum values on the ASHRAE 7-point scale, and the average value. For example, in the cafeteria on the ground floor, there were 170 participants with a minimum thermal perception vote of 0 and a maximum of +3.0. The average thermal perception vote for this space was +1.5. Similar information is provided for the garden area on the ground floor, the seminar room on the ground floor, and the first, second, and third floors. These values offer insights into the participants' subjective perception of thermal comfort in different areas of the building.

The questionnaire was designed to reflect the respondent's subjective assessment of the actual thermal environment. The questionnaire utilized in this study was divided into two sections. Part 1 aimed to collect general information about participants' workplace space circumstances. Participants' gender, age and the number of years they had resided in Malaysia were among the personal information collected in Part 1 of the questionnaire. For office spaces, information was needed regarding office space typology, type of ventilation, number of people utilizing the room, number of windows available for opening, and the location of each participant's workstation concerning an external window. The main contents of the questionnaire include respondents' backgrounds, such as gender and age. Respondents' clothing and activity rate. The respondents were usually involved in sitting and conducting their work when answering the questionnaire after a thirty-minute exposure to the environment. The ASHRAE seven-point thermal sensation scale was used in the survey questionnaire to help respondents express their thermal sensations. For respondents' subjective thermal comfort, a 7-point scale was adopted to qualify respondents' thermal comfort vote Reactions to thermal sensation.

On the other hand, part 2 of the questionnaire was given at both stages of the field study activity, using a longitudinal approach. As a result, this study employed a longitudinal approach to administering part 2 of the thermal comfort surveys over both survey rounds. Every day of the survey, each participant will receive two thermal comfort surveys: one in the morning (between 9 a.m. and 12 p.m.) and one at the end of the day (between 1 p.m. and 4 p.m.). Throughout the two survey rounds, this process was during physical measurements.

970 respondents answered the questionnaire. The questionnaire was distributed to the occupants of UTHM library students, staff, and workers during the morning and afternoon.

Table 2
The Mean TSV values obtained from the questionnaire.

ASHRAE 7-point scale		Cafeteria	Garden	Seminar Room
Hot	+3	0	0	0
Warm	+2	0	0	0
Slightly warm	+1	20	10	1
Neutral	0	30	36	30
Slightly cool	-1	0	4	19
Cool	-2	0	0	0
Cold	-3	0	0	0
Average TSV		+0.4	+0.12	-0.36

Table 3
Summary of the participants' thermal perception votes across different office spaces.

	No. Total = 970	ASHRAE 7-point scale		
		Min	Max	Avg.
Ground floor(cafeteria)	170	0	+3.0	+1.5
Ground floor(garden)	166	-1.0	+3.0	+1.0
Ground floor (Seminar room1)	150	-2.0	+1.0	-0.5
1st floor	184	-1.0	+1.0	0
2nd floor	150	-2.0	+2.0	0
3rd floor	150	-2.0	+2.0	0

Table 4 presents a comparison of various parameter measurements in different spaces within the UTHM library. The spaces analyzed include semi-outdoor areas (cafeteria and garden), indoor spaces (seminar room, 1st and 3rd floors), and indoor open spaces (2nd floor). The sample size for each space varies, ranging from 150 to 484 respondents. Operative temperature, which represents the average temperature perceived by individuals, shows slight variations across the spaces. The semi-outdoor spaces (cafeteria and garden) have higher mean operative temperatures of 27.3 °C and 27.9 °C, respectively. The indoor spaces and indoor open spaces have lower mean operative temperatures, ranging from 23.3 °C to 23.8 °C. Mean air temperature closely aligns with the operative temperature, reflecting similar patterns across the different spaces. The semi-outdoor spaces have higher mean air temperatures compared to the indoor and indoor open spaces. Air velocity, representing the movement of air, shows slight variations as well. The indoor open spaces on the 1st and 3rd floors exhibit the lowest mean air velocities of 0.53 m/s and 0.98 m/s, respectively. The semi-outdoor spaces (cafeteria and garden) have slightly higher mean air velocities compared to the indoor spaces. Relative humidity, which indicates the moisture content in the air, exhibits slight variations across the spaces. The semi-outdoor spaces have higher mean relative humidity values (around 73.5%–78.2%) compared to the indoor and indoor open spaces, where the mean relative humidity ranges from 71.9% to 73%. Mean radiant temperature, representing the average temperature of surrounding surfaces, shows variations across the different spaces. The semi-outdoor spaces (cafeteria and garden) have higher mean radiant temperatures compared to the indoor and indoor open spaces.

4. Quantitative analysis

In this study, it is crucial to establish a standard framework to ensure that the research results align with recognized standards and fulfill the required criteria. The ASHRAE Standard 55–2020: Guidelines for Thermo-Ecological Environment for Human Occupancy and the Malaysia Department of Safety and Health (DOSH) Industry Code of Practice on Indoor Air Quality (2010) serve as essential references for analyzing building comfort levels. Table 5 presents specific physical parameters and their acceptable ranges, as outlined in the standards.

Table 5
Acceptable range for specific physical parameters for buildings [16,17].

Parameters	Malaysia standard	ASHRAE Standard 55
Air Temp. (C)	24–26	23.5–26
Relative Humidity (%)	35–70	30–60
Air Velocity (m/s)	0.15–0.50	<0.25

These sources provide valuable information for research. The study also incorporates guidelines for the number of sampling points based on the total floor area, as indicated in Table 6.

Additionally, the measuring instruments utilized must meet specific range and accuracy requirements, as depicted in Table 7.

Special precautions, such as radiation protection for air temperature sensors, should be implemented. The research employed the KIMO instrument model AMI 310 with a black globe sensor with TSI VelociCalc Plus Velocity Meter (Model 8386) device to measure air temperature, relative humidity, air velocity, and mean radiant temperature as shown in Figs. 6 and 7 was used to measure air velocity, air temperature, relative humidity, and differential pressure.

Physical measurements were conducted over one year, with data collected for 6 h each day during critical periods of anticipated occupancy. The measurement intervals adhered to the recommended timeframes specified for each parameter, and the measurement equipment was positioned in each the floor as shown in Fig. 7.

The data was collected at two consecutive time intervals for each location, as shown in Fig. 8. The prevailing mean outdoor temperature was determined by measuring the mean outdoor dry-bulb temperature during study. The measurement device was placed outdoors near the selected region of interest. It was deliberately placed beneath a shaded roof structure to avoid direct sunlight exposure.

The calculation of operative temperatures in this study was performed using Equation (1):

$$to = Ata + (1 - A)tr \quad (1)$$

In the equation, *to* represents the operative temperature, *ta* denotes the

Table 6
Minimum number of sampling points.

Total Floor Area (m2)	Minimum Number of Sampling Points
<3000	1 per 500m2
3000 - < 5000	8
5000 - < 10,000	12
10,000 - < 15,000	15
15,000 - < 20,000	18
20,000 - < 25,000	21
≥30,000	1 per 1200 *m*2

Table 4
Comparative analysis of parameter measurements in different spaces within UTHM library.

Parameter measurement	Semi-outdoor spaces		Indoor spaces			Indoor open spaces
	Cafeteria	Garden	Seminar room	1rdfloor	3rdfloor	2rdfloor
Sample Size	170 336	166	150 484	184	150	150
Mean Operative temperature (C)	27.3 27.6	27.9	23.3 23.5	23.5	23.8	23.7
Mean Air Temperature (C)	27.3 27.6	27.9	23.7 23.6	23.5	23.7	23.7
Mean Air velocity (m/s)	0.91 0.98	1.06	0.46 0.53	0.55	0.6	0.58
Mean Relative humidity (%)	78.2 78.2	78.2	71.9 73	73.7	73.5	72.7
Mean Radiant temperature (C)	27.5 27.7	27.9	22.6 23.3	23.5	24	23.6

Table 7
Instrument measurement range and accuracy.

Quantity	Measurement Range	Accuracy
Temperature of the air	10 °C–40 °C (50 °F–104 °F)	±0.2 °C (0.4 °F)
Temperature of the radiant mean	10 °C–40 °C (50 °F–104 °F)	±1 °C (2 °F)
Temperature in the plane of radiant heat	0 °C–50 °C (32 °F–122 °F)	±0.5 °C (1 °F)
Temperature at the surface	0 °C–50 °C (32 °F–122 °F)	±1 °C (2 °F)
relative humidity	25%–95% rh	±5% rh
Air velocity	0.05–2 m/s (10–400 fpm)	±0.05 m/s (±10 fpm)
Radiation with a specific direction	−35 W/m2 to +35 W/m2 (−11 Btu/h·ft2 to +11 Btu/h·ft2)	±5 W/m2 (±1.6 Btu/h·ft2)

Fig. 6. KIMO instrument model used for physical measurement.

average air temperature, tr represents the mean radiant temperature, and A is a variable that depends on the average air velocity.

The findings of the measurements taken during the study period for the indoor-outdoor air temperature recorded over the course of several months, providing insights into the temperature variations experienced during different seasons. The data collected from these measurements are essential for understanding the thermal conditions and their impact on the overall comfort levels within the studied environment.

Table 8 presents the outdoor air temperature recorded each month, including the minimum, maximum, and average values. The minimum temperature ranges from 24 °C in December to 26.8 °C in June, while the maximum temperature ranges from 33 °C in November to 34.2 °C in March. The average temperature varies from 28.5 °C in December to 30.45 °C in June. The data indicate seasonal variations in the outdoor air temperature, with higher temperatures observed during the summer months (June to August) and lower temperatures in the winter months (December to February). These fluctuations in temperature can have a significant impact on the thermal conditions experienced by individuals within the studied environment. Understanding these temperature patterns is crucial for assessing the effectiveness of the thermal management strategies employed and for evaluating the comfort levels of the occupants. The recorded temperatures provide valuable information for analyzing the thermal characteristics of the environment and can be used in conjunction with other data to assess the overall thermal comfort and energy management of the studied space. In the next part of this

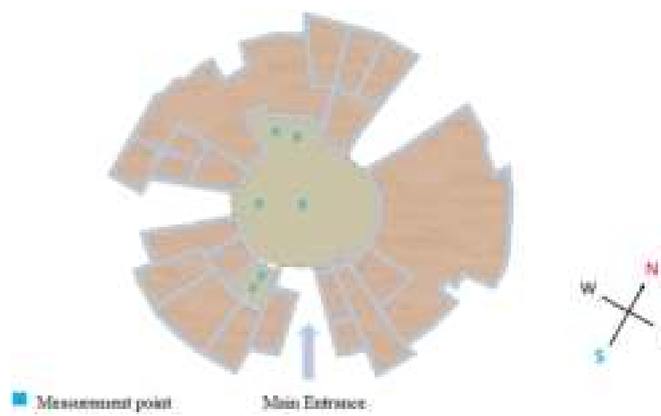

Fig. 8. The locations of measurement points on the UTHM Library ground floor.

Fig. 7. Physical Measurement location.

Table 8
Outdoor air temperature variation over the study period.

Month		Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
Outdoor Air Temperature (C)	Min	26.5	26.2	26.8	25.9	26.6	26.8	26	25	24	24.5	25.3	26.4
	Max	33.8	33.6	34.1	33.2	33	33.5	34	33	33	33.7	33.9	34.2
	Avg	30.15	29.9	30.45	29.55	29.8	30.15	30	29	28.5	29.1	29.6	30.3

disscussion we will present the average data collected during measurement in each space.

The data includes measurements of air temperature, relative humidity, air velocity, and mean radiant temperature. The measured data spans a period of several months, allowing for a comprehensive analysis of the variations in these parameters over time. This data is crucial in understanding the thermal conditions and environmental comfort experienced in the library cafeteria.

The average air temperature in the UTHM library ground floor cafeteria ranged from a minimum of 25.9 °C to a maximum of 30.0 °C. The temperature showed a gradual decrease from June to December, with the lowest average temperature recorded in December at 25.9 °C. There was a slight increase in average temperature from January to March, reaching a peak of 28.3 °C in March. The relative humidity in the cafeteria ranged from a minimum of 64.3% to a maximum of 90.1%. The humidity levels remained relatively consistent throughout the study period, with an average ranging from 75.3% to 81.9%. There was a slight dip in humidity in November, with an average of 75.6%. The air velocity measurements in the cafeteria varied from a minimum of 0 m/s to a maximum of 1.98 m/s. The average air velocity ranged from 0.8 m/s to 1.05 m/s. These values indicate a moderate level of air movement within the cafeteria space. The mean radiant temperature in the cafeteria ranged from a minimum of 25.1 °C to a maximum of 30.0 °C. The average means radiant temperature varied from 26.7 °C to 28.0 °C. The values suggest a relatively consistent mean radiant temperature throughout the study period.

The data collected provides a comprehensive understanding of the thermal environment in the UTHM library ground floor cafeteria. These parameters are essential for evaluating the thermal comfort experienced by individuals in that semi-outdoor space. By analyzing the relationship between these environmental factors and the participants' thermal comfort perceptions, we can gain insights into the impact of the thermal environment on individuals' well-being and comfort.

The graph of Fig. 9 illustrates the average environmental parameter data in UTHM library ground floor-cafeteria (semi-outdoor space) that includes air temperature, relative humidity, and mean radiant temperature. From the chart, October recorded the highest relative humidity (M = 81.9 °C). On the other hand, April 2022 recorded the highest air temperature (M = 28.9 °C) and mean radiant temperature (M = 28.1 °C).

For the garden area of the UTHM library. The data provides insights into the average air temperature, relative humidity, air velocity, and mean radiant temperature over the course of several months. The recorded air temperature shows a range of minimum and maximum values, indicating variations between 25.0 °C and 31.7 °C. The average temperature ranged from 26.75 °C to 29.85 °C, with a gradual increase observed from January to March. Relative humidity measurements reveal a range of minimum and maximum values between 62.6% and 90.4%, respectively. The average relative humidity varied from 73.5% to 82.0%, showing slight fluctuations throughout the study period. The air velocity data indicates consistent minimum values of 0 m/s, while the maximum values ranged from 1.92 m/s to 2.4 m/s. The average air velocity ranged from 0.96 m/s to 1.2 m/s, suggesting moderate airflow within the garden space. Mean radiant temperature measurements display variations between 26.0 °C and 30.6 °C for the minimum and maximum values, respectively. The average mean radiant temperature fluctuated between 27.35 °C and 28.95 °C, remaining relatively stable throughout the study period.

The graph of Fig. 10 illustrates the average data collected in the UTHM library ground Floor-Garden (semi-outdoor space) over a period of 12 months. It provides valuable insights into the temperature and humidity conditions experienced within the Garden. The shaded area between the outdoor air temperature and air temperature curves highlights the temperature range. The blue line represents the outdoor air temperature, which exhibits slight variations throughout the year. The red line depicts the air temperature inside the Garden, consistently lower than the outdoor air temperature. The magenta line represents the mean radiant temperature, offering an understanding of the average temperature perceived by individuals in space. The green line corresponds to the relative humidity, showcasing fluctuations over the months. The graph enables an analysis of the thermal comfort and indoor environmental conditions within the ground floor Garden, aiding in the evaluation and potential improvement of the space's comfort levels.

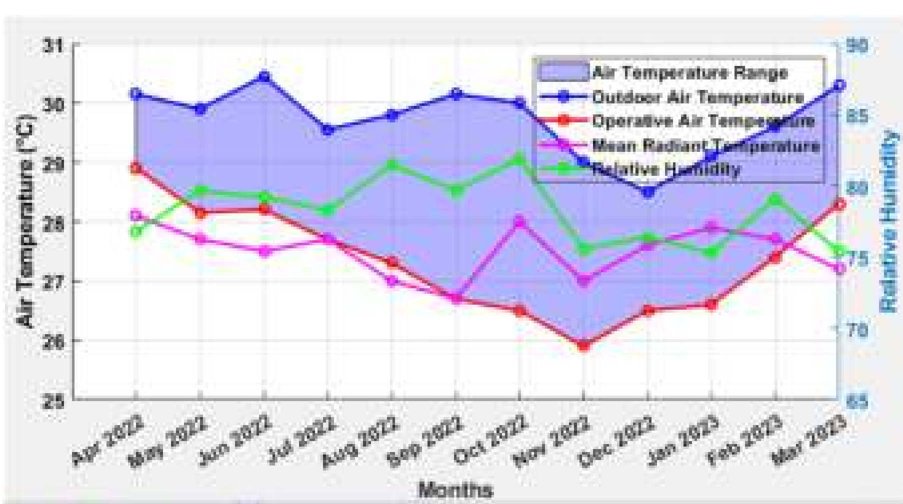

Fig. 9. Graphical representation of the average Data in UTHM library ground floor-cafeteria (semi-outdoor space).

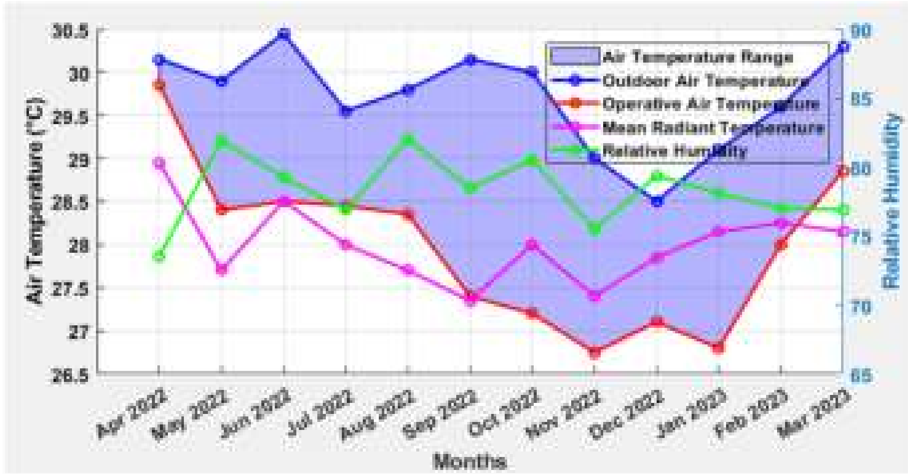

Fig. 10. Average Data in UTHM library ground Floor-Garden (semi-outdoor space).

For the seminar room (indoor space) on the ground floor of the UTHM library. The recorded parameters include air temperature, relative humidity, air velocity, and mean radiant temperature over the course of several months. The air temperature in the seminar room ranged from a minimum of 22.3 °C to a maximum of 25.5 °C. The average temperature varied between 23.5 °C and 24.3 °C. These values indicate a relatively consistent and comfortable temperature range within the seminar room throughout the study period. Relative humidity measurements show variations between 63% and 80.5%, with an average ranging from 70.2% to 73.9%. The recorded values indicate a moderate level of humidity, contributing to a comfortable indoor environment. Air velocity measurements indicate minimal airflow, with values ranging from 0 m/s to a maximum of 0.96 m/s. The average air velocity remains relatively low, varying from 0.42 m/s to 0.56 m/s. These findings suggest a calm and still indoor environment in the seminar room. Mean radiant temperature, which represents the perceived temperature based on the heat exchange between occupants and their surroundings, varied between 19.2 °C and 25.4 °C. The average means radiant temperature ranged from 22.1 °C to 23.35 °C. These values indicate a relatively consistent thermal condition in the seminar room.

The bar chart of Fig. 11 shows seminar room 1 (indoor space). From the figure, March 2023 had the highest air temperature (M = 24.3 C), while July 2022 had the least (M = 23.5 C).

For the first floor (indoor space) of the UTHM library. The recorded parameters include air temperature, relative humidity, air velocity, and mean radiant temperature over several months. The air temperature on the first floor ranged from a minimum of 23 °C to a maximum of 24.6 °C. The average temperature varied between 23.4 °C and 23.9 °C. These values indicate a relatively consistent and comfortable temperature range within the indoor space throughout the study period. Relative humidity measurements show variations between 63.1% and 85%, with an average ranging from 72.9% to 76.55%. The recorded values indicate a moderate to high level of humidity, suggesting a slightly more humid environment compared to the ground floor and garden areas. Air velocity measurements indicate minimal airflow, with values ranging from 0 m/s to a maximum of 1.3 m/s. The average air velocity remains relatively low, varying from 0.48 m/s to 0.65 m/s. These findings suggest a calm and still indoor environment on the first floor of the library. Mean radiant temperature, which represents the perceived temperature based on the heat exchange between occupants and their surroundings, varied between 23 °C and 24.3 °C. The average means radiant temperature ranged from 23.35 °C to 23.75 °C. These values indicate a relatively consistent thermal condition in the first-floor indoor space.

Fig. 12 above represents the average data in the UTHM library first floor (indoor space). The bar chart shows that the floor had a higher relative humidity than any other environmental parameter. From the figure, Jun 2023 had the highest air temperature (M = 24.6 °C).

For the second floor (the indoor open space) of the UTHM library. The recorded parameters include air temperature, relative humidity, air

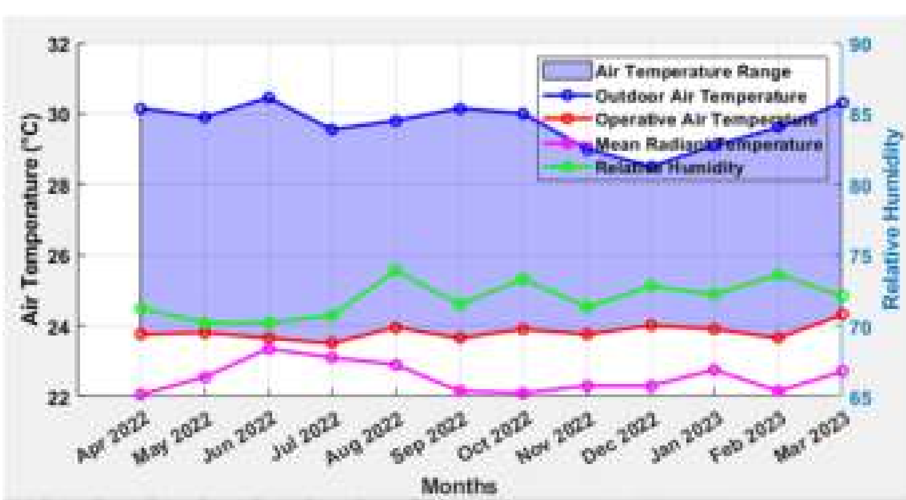

Fig. 11. Graphical representation of Average Data in UTHM library ground floor – seminar room1(indoor space).

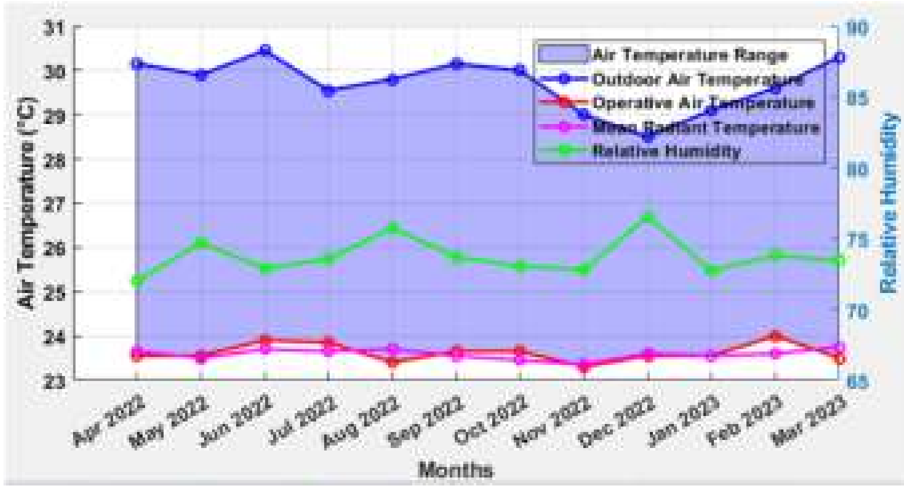

Fig. 12. Bar chart of average data in UTHM library first floor (indoor space).

velocity, and mean radiant temperature for various months. The air temperature on the second floor ranged from a minimum of 23 °C to a maximum of 24.5 °C. The average temperature varied between 23.5 °C and 23.85 °C. These values indicate a relatively consistent and comfortable temperature range within the indoor open space throughout the study period. Relative humidity measurements show variations between 63.2% and 84.3%, with an average ranging from 71.35% to 74.95%. The recorded values suggest a moderate to slightly high level of humidity, indicating a somewhat humid environment on the second floor. Air velocity measurements indicate minimal airflow, with values ranging from 0 m/s to a maximum of 1.3 m/s. The average air velocity remains relatively low, varying from 0.5 m/s to 0.65 m/s. These findings suggest a calm and still indoor environment on the second floor of the library. Mean radiant temperature, which represents the perceived temperature based on the heat exchange between occupants and their surroundings, varied between 23 °C and 24.2 °C. The average means radiant temperature ranged from 23.4 °C to 23.75 °C. These values indicate a relatively consistent thermal condition in the indoor open space on the second floor.

Fig. 13 represents the average data collected on the second floor of the UTHM library, which consists of indoor spaces with indoor open areas, over 12 months. It provides insights into the air temperature and relative humidity conditions experienced within the second floor. The shaded region between the outdoor air temperature and air temperature curves illustrates the range of air temperatures. The blue line corresponds to the outdoor air temperature, showing slight variations throughout the year. The red line represents the air temperature inside the second floor, which remains relatively stable with minimal fluctuations. The magenta line represents the mean radiant temperature, providing an indication of the average temperature perceived by individuals in space. The green line represents the relative humidity, which displays some variations over the months. This graph enables the analysis of indoor thermal comfort and environmental conditions on the second floor, aiding in evaluating and potentially improving the space's comfort levels and overall indoor environment.

For the third floor of the UTHM library, which includes both indoor and indoor open spaces. The parameters measured include air temperature, relative humidity, air velocity, and mean radiant temperature for different months. The recorded air temperature ranges from a minimum of 23 °C to a maximum of 24.3 °C. The average temperature varies between 23.55 °C and 23.9 °C. These values indicate a relatively stable and comfortable temperature range within the indoor spaces of the third floor throughout the study period. Relative humidity measurements show variations between 64.2% and 83.4%, with an average ranging from 72.5% to 75.2%. The recorded values suggest a moderate to slightly high level of humidity, indicating a somewhat humid environment on the third floor. Air velocity measurements indicate minimal airflow, with values ranging from 0 m/s to a maximum of 1.3 m/s. The average air velocity remains relatively low, varying from 0.56 m/s to 0.65 m/s. These findings suggest a calm and still indoor environment on

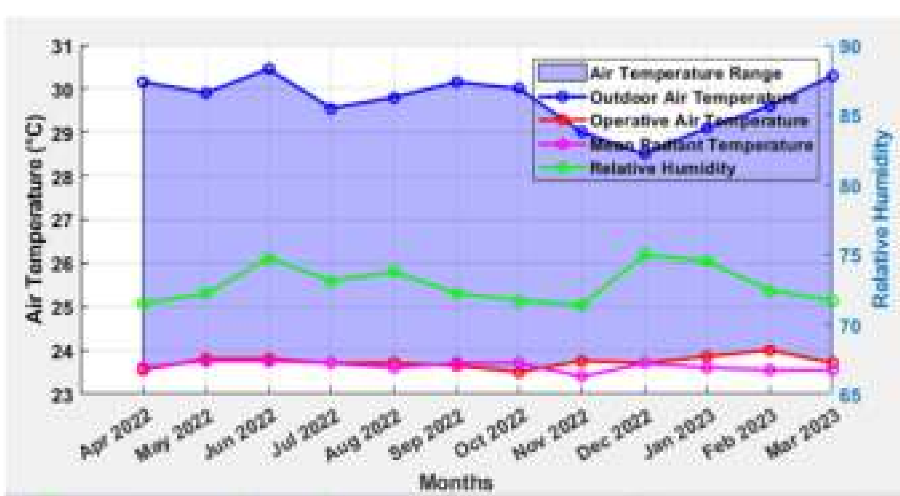

Fig. 13. Average Data in UTHM library Second floor (indoor with indoor open spaces).

the third floor of the library. Mean radiant temperature, which represents the perceived temperature based on the heat exchange between occupants and their surroundings, ranges from 23.3 °C to 24.8 °C. The average mean radiant temperature varies between 23.85 °C and 24.25 °C. These values indicate a relatively consistent thermal condition within the indoor and indoor open spaces on the third floor.

The graph of Fig. 14 represents the average data for the third floor of the UTHM library, specifically focusing on indoor areas with indoor open spaces. The shaded area between the blue and red lines represents the range of air temperatures between the outdoor air temperature and the air temperature on the third floor. The blue line depicts the outdoor air temperature, while the red line represents the air temperature on the third floor. The magenta line indicates the mean radiant temperature, which is an important factor in thermal comfort. The green line represents the relative humidity, providing insight into the moisture content in the air. These visualizations help understand the variations in temperature and humidity throughout the year, enabling better analysis and optimization of the indoor environment in the library's third floor.

5. Results and discussion

The impact of required workplace attire on workers' perceptions of and responses to thermal conditions is a critical feature of office environments in Johor Bahru, Malaysia's Tropical Region climate. The main goal is to examine the local office occupants' adaptive thermal comfort in typical work conditions, highlighting the significance of controlled office dress for thermal comfort. Building on the previously mentioned results, this part thoroughly reviews the study's primary research findings. It also highlights how important the study is to better our understanding of thermal comfort in office environments, and it ends by making insightful recommendations for future research areas in this field. We conducted a thermal comfort field study in Johor Bahru, Malaysia, concentrating on the UTHM library to meet the study's objectives. The study covered various sites, including indoor open areas, interior locations, and semi-outdoor spaces. Using quantitative and qualitative methods for data collection and analysis, we used a mixed-mode methodological strategy to ensure a thorough knowledge of office workers' experiences with thermal comfort.

The thermal comfort levels in the various places under consideration were determined using the human reaction technique, the Thermal Sensation Vote (TSV), and physical measurement method (PMV). Table 9 compared the UTHM Library case study areas to the ASHRAE 55–2020 standard. The table includes human response TSV data and physical measurements, including the PMV.

The findings of our study provide insightful insights into the thermal comfort experienced by office occupants in the UTHM Library's diverse spaces. The human reaction technique revealed a TSV value of +0.26 in the semi-outdoor areas, indicating that people using these areas enjoyed a comfortable climate, a testament to the well-designed and agreeable environment. In addition, the PMV measurements confirmed a remarkable 90% acceptance limit, demonstrating that the thermal conditions in these semi-outdoor spaces fall within the permissible comfort range specified by the ASHRAE 55–2020 standard, which states that comfort is attained when the Predicted Mean Vote (PMV) ranges from −0.5 to +0.5. These spaces provide occupants with a comfortable thermal environment, which is essential for fostering productivity and satisfaction. In contrast, the TSV rating for indoor open areas was −0.14, indicating a slightly more negative temperature perception. However, the actual PMV reading of −0.25 is still well within the acceptable range specified by ASHRAE. Similarly, the perception of indoor spaces was more negative, as indicated by the TSV score of −0.34. Nonetheless, the PMV reading of −0.22 confirms that the internal environments are within the acceptable range specified by ASHRAE. This comparison demonstrates that the case study areas in the UTHM Library generally meet the ASHRAE 55–2020 Standard's thermal comfort requirements. Thus, the study demonstrates that the thermal conditions in these spaces adhere to the recommended guidelines, assuring the health and comfort of the library's patrons.

Table 9
Comparison of case study spaces with ASHRAE standard.

UTHM Library Spaces	Human Response TSV	Physical measurement PMV	ASHRAE 55–2020 standard
Semi-outdoor spaces	+0.26	90% Acceptability limit	complies
indoor open spaces	- 0.14	- 0.25	complies
indoor spaces	- 0.34	- 0.22	complies

Our exhaustive research delved further into the effect of garment insulation on thermal comfort in various library settings. The study's regression analysis revealed additional insights into the comfort ranges for clothing insulation in different environments. The human response to flexible clothing with natural ventilation indicated a comfort range between 0.59 and 0.74 clo, with an acceptance rate of 76%, these results align with ASHRAE Standard 55–2020, which recommends an adjustable thermal comfort range of 0.5–1.0 clo resulting in neutral to temperature sensations (scores between −0.5 and + 0.5). Similarly, based on physical measurements, the comfort range for flexible clothing in Malaysia was between 0.35 and 0.80 clo, with a 93% acceptability rate, conforming to the ASHRAE 55 Standard. In contrast, the comfort range

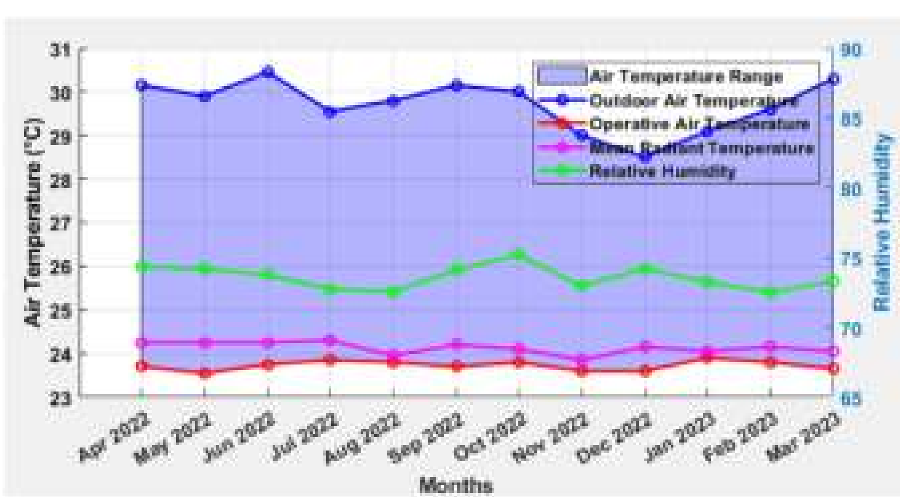

Fig. 14. Average Data in UTHM library Third floor (indoor with indoor open spaces.

based on physical measurements for air-conditioned stringent uniform policies was 0.75–1.45 clo, with a 60% acceptability rate whereas the human response indicated a range of 0.74–1.2 clo. With a 50% acceptability rate. These findings imply an overachievement of the ASHRAE 55 Standard for strict uniform clothing, which recommends an adjustable thermal comfort range of 0.5–1.0 clo. The study demonstrates the importance of clothing options in allowing office employees to adjust their comfort levels, with those with more wardrobe options expressing greater satisfaction, these data highlight the need for higher clothing insulation values in climate-controlled environments. Using extant literature as a comparison, our study's findings align with those of similar studies conducted in various climate zones around the world. The extraordinary consistency of thermal comfort neutralities observed in neighboring countries and other hot and humid regions provides additional support for the findings of our study. It highlights the relevance and significance of understanding thermal comfort in various environmental contexts and highlights the significance of controlled office attire policies for promoting employee health and productivity in tropical climates. Given these considerations, establishing a novel standard for clothing insulation tailored to workers in the Malaysian climate is paramount, to highlight the relevance and significance of understanding thermal comfort in various environmental contexts and highlights the significance of controlled office attire policies for promoting employee health and productivity in tropical climates. When considering the average mechanism, the comfort range for flexible clothing emerged as 0.47 to 0.77 Clo, boasting an 85% acceptability rate. In contrast, the comfort range for strict uniform clothing was identified as 0.74 to 1.32 Clo, with a 55% acceptability rate. Table 10: presents a comprehensive overview of clothing insulation comfort ranges (measured in Clo) alongside average comfort values derived from both physical measurement and human response methods.

The data analysis revealed a neutral comfort temperature range, determined through regression analysis. For semi-outdoor spaces with natural ventilation, the comfort temperature range based on the physical measurement method was between 24.5 and 31.3, with a 90% acceptability rate. These results align with the ASHRAE 55–2020 Standard. Similarly, based on the human response method, the comfort temperature range for semi-outdoor spaces fell between 22.1 and 29.2, also within the ASHRAE 55 Standard. Regarding indoor spaces with air-conditioning, the comfort temperature range determined through physical measurements was between 22.9 and 25.6. These findings are consistent with the ASHRAE 55–2020 Standard. Additionally, based on the human response to indoor spaces, the comfort temperature range was between 22.2 and 23.8, aligning with the ASHRAE 55 Standard. For indoor open spaces with air-conditioning, the comfort temperature range based on physical measurements was determined to be between 23.1 and 25.1, meeting the ASHRAE 55–2020 Standard. Similarly, the comfort temperature range for indoor open spaces, based on the human response method, was found to be between 22.6 and 25.9, within the ASHRAE 55 Standard, Table 11: Presents the comfort temperature range for case study spaces.

The study revealed a neutral temperature of 26.7 °C, accompanied by 90% acceptable comfort limits ranging from 23.3 °C to 30.2 °C. Remarkably, these results align with the comfort neutralities observed by researchers in other hot and humid climate zones worldwide, particularly in neighboring countries. According to the study's findings, people perceive a broader range of acceptable temperatures in semi-outdoor rooms with natural ventilation when compared to indoor spaces with air conditioning and indoor open spaces with air conditioning. These findings have significant implications for designing and using semi-outdoor spaces as functional public spaces. According to the study, semi-outdoor areas might be practical solutions for creating pleasant surroundings while promoting sustainability and energy efficiency. By combining natural ventilation and considering people's comfort needs, these sites can provide valuable solutions for public spaces. The findings of this study can also assist policymakers in developing energy policies that prioritize economics, environmental responsibility, and efficiency. The study also underlines the need to understand and accommodate office workers' thermal comfort demands. Controlling the thermal conditions in buildings can improve productivity, well-being, and energy efficiency. This underscores the need to consider people's comfort demands while planning and operating office settings.

Table 11
The comfort temperature range for case study spaces.

UTHM Library Spaces	Sample size	-0.5 ≤ Comfort Range ≤ +0.5 (°C)		Average Comfort Temperatures(°C)
		PMV	TSV	
Semi-outdoor	336	24.5–31.3	22.1–29.2	23.3–30.2
indoor	484	22.9–25.6	22.2–23.8	22.5–24.7
Indoor open	150	23.1–25.1	22.6–25.9	22.8–25.5

6. Conclusion

This study has yielded vital insights regarding the thermal comfort of office employees at the UTHM Library in Johor Bahru, Malaysia. The study identified several factors that affect thermal comfort, such as workplace attire regulations and environments with diverse ventilation techniques. Notably, the study emphasized the importance of clothing insulation in obtaining individual thermal comfort. Employees who were permitted to choose their clothing insulation from various options reported greater thermal satisfaction than those required to adhere to strict uniform policies, highlighting the significance of offering a variety of clothing options to accommodate individual comfort preferences. In addition, the study revealed that semi-outdoor locations with natural ventilation offered a broader temperature range than interior chambers with air conditioning. This research provides valuable insights for designing public spaces that employ natural ventilation to create comfortable environments while promoting sustainability and energy efficiency. The study's results contribute to the existing knowledge on thermal comfort in office environments and offer suggestions for improving workspace design and management. The prioritization of thermal comfort for office employees can improve the building's productivity, occupants' well-being, and energy efficiency. Facility managers, architects, and policymakers can use the findings as a resource for designing ergonomic work environments that prioritize the thermal comfort and well-being of occupants. Implementing the study's recommendations can result in office spaces that promote increased productivity and well-being, enhancing health, comfort, and energy efficiency.

As the study of adaptive thermal comfort in Malaysia is still in its infancy compared to Western nations, there are numerous opportunities for future research within the context of the climate of tropical regions. To advance knowledge of thermal comfort in Malaysia, the following research directions are suggested:

Impact of Air Velocity on Thermal Perception and Adaptation: It is recommended that further research be conducted in the local context to

Table 10
Summary of Clothing Insulation comfort with ASHRAE Standard.

Types of clothing	Human Response method	Physical measurement method	Average Clothing insulation (Clo)	ASHRAE 55–2020 standard
Flexible	0.59–0.74	0.35–0.80	0.47–0.77	Complies
Strict uniform	0.74–1.20	0.75–1.45	0.74–1.32	not comply

investigate and compare the impact of air velocity on thermal perception. Understanding how various air velocities affect the thermal comfort and adaptation of individuals in Malaysia's particular climate conditions will provide valuable insights for enhancing comfort strategies and optimizing energy consumption.

Potential Energy-Saving and Building Design Strategies It is essential to prioritize energy consumption calculations and simulations when assessing the potential energy-saving benefits of adaptive thermal comfort strategies. The evaluation of the effect of these measures on energy consumption will inform the development of sustainable and energy-efficient building design strategies in Malaysia, thereby promoting environmentally responsible and comfortable indoor environments.

By investigating these research avenues, the knowledge of adaptive thermal comfort in Malaysia can be expanded, resulting in more context-specific recommendations and guidelines. These studies will provide architects, engineers, and policymakers with invaluable information for developing thermal comfort, energy efficiency, and sustainability strategies for the built environment. Ultimately, this research will enhance the health, productivity, and environmental performance of buildings in Malaysia's tropical climate.

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.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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