Effect of Office Design Characteristics and Anthropometrics on Thermal Comfort in Malaysian Universities Air-Conditioned Buildings

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Abstract. Apart from indoor environmental and personal factors, contextual factors have significantly influenced several thermal comfort studies. In air-conditioned spaces, thermal comfort is conveniently attainable by adjusting the temperature settings, but indoor design elements might alter thermal perceptions and provide adaptive opportunities. This study examines the influence of office design characteristics and anthropometrics on thermal comfort parameters and perceptions. Nineteen university offices in Kuala Lumpur and Shah Alam, comprised of twelve shared and seven private spaces, were investigated, and 628 responses were collected from 42 participants with even gender distributions. The results showed that room occupancy and size were statistically significant with Griffiths' comfort temperature. Offices with five or more people had lower mean comfort temperature (24.1 °C) than private offices (25.0 °C). The mean comfort temperature in offices larger than 80 m^2 was 23.7 °C with warmer thermal preference, while offices smaller than 40 m^2 were approximately one-degree Celsius higher. Offices with no shading device, window blinds opened, and tiled floorings had mean comfort temperatures higher than 25.0 °C. The findings also indicated that offices with more than a 60% glazing ratio have a slightly higher mean comfort temperature at 24.9 °C. The thermal sensation during closed blinds was much cooler than opened ones. The anthropometry of the human body impacts how heat is regulated; thus, respondents with higher Body Mass Index (*BMI*) and above-average body surface area (higher than 1.7 m^2) had significantly lower comfort temperatures and preferred more humid surroundings. Mean comfort temperature was statistically significant with *BMI* with a noticeable difference between underweight (25.1 °C), normal (24.5 °C), and obese (23.9 °C) *BMI*s. In this study, it is recommended that *BMI* be considered when positioning occupants in shared offices, and window blinds are an integral shading device for adjusting indoor thermal comfort levels.

1 Introduction

Thermal comfort in a built environment can be interpreted as a psychological condition that conveys satisfaction with the thermal environment via a subjective assessment [1]. Building energy consumption is responsible for about 40% of global energy use, and half of the energy in most commercial buildings is utilized to maintain indoor thermal comfort [2, 3].

In Malaysia, where the weather is hot and humid all year round, indoor thermal conditions are regulated using the air-conditioning and mechanical ventilation (ACMV) system. A recent study in a local institutional building revealed that ACMV systems consumed the highest amount of building energy and were liable for 34% of the electricity bill [4]. The excessive energy use to maintain thermal satisfaction is justified considering the strong interrelation between thermal discomfort and poor work performance [5–7]. However, considering the rapid urbanization and climate change, the cooling load of office buildings in Malaysia is projected to increase by 8.1% in the next 30 years [8]. With global demand to reduce carbon emissions and promote energy conservation, it is imperative to identify non-consumable elements that can mitigate thermal discomfort.

Researchers have examined several contextual elements for properly comprehending thermal comfort in realistic circumstances. The adaptive model accommodates behavioural, psychological, and physiological changes, rather than with heat exchange theory [9–12]. By simply altering posture, clothing, and movement or activity, humans can adapt to their surroundings. Additionally, the dynamic equilibrium between the environment and thermal needs can be achieved by adjusting windows, and blinds, or modifying the heating and cooling systems [13, 14].

In their investigation into how gender affects thermal comfort, Maykot *et al.* [15] discovered that female participants experienced higher comfort temperatures

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than male participants, particularly while using air-conditioners (AC). Male tenants are frequently connected with a warm feeling, and vice versa for female residents, according to Rupp *et al.* [16]. The results are consistent with climate chamber tests conducted in China and Hong Kong, which found that men liked slightly cooler surroundings while women favoured slightly warmer ones [17, 18]. Similar findings were found in a study conducted in subtropical Taiwan by Tsay *et al.* [19], which showed that men were more productive at a greater temperature than females were.

A two-year study in humid subtropical Southern Brazil found increased levels of warm discomfort among overweight adults [15, 16], who was also said to have a 30% lower metabolic rate than usual [20] due to their higher body mass index (*BMI*). Indraganti *et al.* [21] found considerably lower comfort temperatures among Qatar, India, and Japan residents as *BMI* increased. In thermal history, it was discovered that people who used air conditioning frequently were more likely to report feeling warm, whilst those who used it infrequently were more likely to report feeling uncomfortably cold [16].

A review on thermal comfort in multiple built environments by Rupp *et al.* [22] mentioned that contextual factors could extend to culture, space layout, architectural landscapes, and other characteristics where adaptive opportunities are obtainable. Current literature has explored contextual factors mainly on demographics (gender and age) and anthropometric data (body mass index, height, weight) [15, 16, 21, 23, 24]. To the best of the authors' knowledge, research on interior design elements in thermal comfort field study is limited.

Meanwhile, studies relating thermal comfort with interior office designs are limited. Thus, several changeable interior arrangements that could influence thermal comforts, like shading devices, flooring, and room occupancy, can be explored. Therefore, this study aims to evaluate the relationship between personal and office interior design characteristics with thermal comfort. Additionally, a suggestion on interior design elements that have the most impact on thermal comfort is expected.

2 Methods

2.1 Study location

Field investigations were conducted in two Malaysian public institutions located in Kuala Lumpur (Universiti Teknologi Malaysia) and Shah Alam (Universiti Teknologi MARA), where the Köppen climate group is A_f (hot and humid). The investigated buildings use the air-conditioning and mechanical ventilation (ACMV) system with split air-conditioners (AC). Information on the surveyed buildings is listed in Table 1. Buildings A, B, and C in Kuala Lumpur mainly accommodate postgraduate workspaces and administrator offices. In Shah Alam, buildings D and E were the Department of Development Office, occupied by university staff. This study was conducted on selected floors of each building; not all occupants volunteered as respondents in the investigated rooms.

The common office design characteristics such as shading device, room area, state of window blinds (open or close), and flooring finish were recorded. Additionally, respondents' proximity to windows was documented, including the glazing ratio of the room, which was estimated using the window-to-wall ratio (WWR) in Equation 1 below.

$$WWR = \frac{\Sigma \text{ Glazing area } (\text{m}^2)}{\Sigma \text{ Gross exterior wall area } (\text{m}^2)} \qquad (1)$$

2.2 Data collection

The indoor thermal parameters (air and globe temperature, air velocity, and relative humidity) were recorded compliant with Standard 55 from the American Society of Heating and Refrigerating and Air-Conditioning Engineers (ASHRAE) [25]. A HOBO data logger with ±0.25 °C temperature and ±2.5% humidity accuracies were used in this study. Prior to field study, the operating conditions of indoor temperature instruments were verified with a ventilation psychrometer and an analogue data logger. Outdoor air temperature and relative humidity in Kuala Lumpur were taken from a weather station located within 1 kilometre radius and in Shah Alam, the outdoor parameters were observed from a national weather station in Subang International Airport, approximately nine kilometres from investigated buildings.

The questionnaire survey was prepared in English with Malay translation in an open source software (Google Form) with contents based on preceding studies in Malaysia [14, 26]. The method of dissemination was through a mobile messaging application, *Whatsapp* and email. The survey includes respondents' demographics (age and gender), anthropometrics (body height and weight), clothing, and activity level (estimated based on ASHRAE [25]). This study's anthropometric data were height and weight, which estimated the respondents' body mass index (*BMI*) by dividing weight by height in m^2 (see Equation 2). The body surface area (A_D) of an average adult is 1.7 m^2, according to ASHRAE Standard 55 [25]. In this study, Dubois' method was used to calculate the surface area, as shown in Equation 3. Respondents were asked to evaluate their thermal sensation, preference, acceptability, and overall comfort in quantified subjective responses, as listed in Table 2. The field study methodology is further elaborated in Ref [27].

$$BMI = \frac{w\ (\text{kg})}{h^2\ (m^2)} \qquad (2)$$

$$A_D = w^{0.425} \times h^{0.725} \times 0.20247 \qquad (3)$$

Where w is weight (kg), h is height (m), and A_D is body surface area (m^2).

Table 1. Information on the surveyed buildings

Building characteristics	 **A**	 **B**	 **C**	 **D**	 **E**
Number of subjects	12	8	9	9	2
Number of samples	174	120	144	133	28
Total floors	10	2	16	1	3
Investigated floors	4, 5, 10	2	8, 13	1	2
Type of investigated offices	Open plan	Open plan	Open plan, private	Open plan, private	Open plan
Floor area (m^2)	4272	542	1244	771	563
Main orientation	East	South-west	South-west	North-east	North-west
Glazing ratio	0.19-0.79	0.18	0.74-0.90	0.20-0.40	0.63
Shading device	Vertical blinds (10th, 5th floor), No blinds (4th floor)	Vertical blinds	Translucent roller blinds	Vertical blinds, roller blinds	Roller blinds
Flooring finish	Ceramic tiles, wool carpet	Wool carpet	Wool carpet	Ceramic tiles and wood	Ceramic tiles

Table 2 Subjective responses with quantified scales

Scale	**Thermal Sensation Vote (*TSV*)**	**Thermal Preference (*TP*)**	**Thermal Acceptance (*TA*)**	**Overall Comfort (*OC*)**
−3	Very cold	-	-	-
−2	Cold	Much warmer	-	-
−1	Slightly cold	A bit warmer	Not acceptable	-
0	Neutral	No change	-	-
1	Slightly hot	A bit cooler	Acceptable	Very uncomfortable
2	Hot	Much cooler	-	Moderately comfortable
3	Very hot	-	-	Slightly uncomfortable
4	-	-	-	Slightly comfortable
5	-	-	-	Moderately comfortable
6	-	-	-	Very comfortable

2.3 Data analysis

The correlation between thermal comfort and personal and interior design elements characteristics was obtained by performing a series of statistical analyses. The t-test examines whether two populations are statistically different, whereas the analysis of variance (ANOVA) determines the outcome for three or more populations. Using the t-test and ANOVA, it was possible to assess the statistical association between thermal perceptions and the contextual variables in this study. Thermal perceptions include the subjective responses from the field survey are listed in Table 2.

The demographics (age and gender) and anthropometrics (*BMI* and body surface area in m^2) are the personal characteristics. Concurrently, the office design characteristics include the number of room occupancy, vicinity to a window, room area in m^2, state of blinds or curtains (open or closed), type of internal shading device, and floor finishing. Age categories were binned into binary functions (0 for less than 30 years) and (1 for more than 30 years). Hence, for the t-test analysis, the variables were age, gender, near window occupancy, and state of blinds or curtains. The remaining characteristics were examined via the ANOVA method.

Griffiths' method was used when the data did not provide accurate regression analysis due to a smaller sample size. This method was initially used on smaller samples, then later estimated that there would be a 3K temperature rise for each comfort in the *TSV* scales based on multiple climate chamber studies [28, 29]. Griffiths' method calculates comfort temperature (T_c) via Equation 4 based on a single comfort vote (*TSV*) under the assumption that there is no adaptation.

$$T_c = T_{op} + \frac{0 - TSV}{\alpha} \tag{4}$$

Where T_{op} is the indoor operative temperature (°C), 0 refers to a neutral condition or can be replaced with any value denoting a neutral state, and α is the Griffiths constant equivalent to the regression coefficient. Nicol *et al.* [30] used an α value of 0.25, 0.33 and 0.50 when implementing Griffiths' method.

Nicol and Humphreys [31] later argued that the Griffiths constant should exceed 0.40 after gathering numerous data from comfort field experiments. They suggested that 0.50 is the most suitable value of α, as adopted in recent comfort studies [14, 26, 32, 33] and used by Taib *et al.* [27], on which the data in this study are based.

The proportion of opening the blinds is estimated using binomial logistic regression analysis adopted in previous studies [34–36]. The relationship between the probability of opening the blinds (P) with temperature is indicated in Equations 5 and 6.

$$\text{logit (P)} = \log\{\text{P}/(1-\text{P})\} = \text{bT} + \text{c} \tag{5}$$

$$\text{P} = \exp(bT + c)/\{1 + \exp(bT + c)\} \tag{6}$$

where exp (exponential function) is the base of the natural algorithm, T is the temperature, b is the regression coefficient, and c is the constant of the regression equation. The data analysis in this study (t-test, ANOVA, and logistic regression) was performed in IBM SPSS Statistics 28 and Microsoft Excel spreadsheet.

3 Results and discussion

3.1 Summary of data

A summary of the collected data is shown in Table 3 and Table 4, cross-tabulated by the study location. There were 467 responses in Kuala Lumpur and 161 in Shah Alam. The studied sites are approximately 30 kilometres apart, sharing similar climate patterns. The mean outdoor air temperature was 30.4 °C in Kuala Lumpur and 29.6 °C in Shah Alam. As for the indoor thermal conditions, the mean operative temperatures were comparable, considering this study's database had implemented a controlled methodology [27]. The mean thermal sensation vote was −0.5, which is slightly on the cooler side and thus reflected on the mean values of comfort temperature with only a 0.4 °C difference in both cities.

The statistical summary of personal variable in Table 4 shows that the mean age in Kuala Lumpur was lower at 29 years due to the inclusion of postgraduate students, mainly in building A and B. In comparison, university staffs in Shah Alam were between 27 and 43 years old, averaging 36 years old. The metabolic rate was based on activities in ASHRAE Standard 55, including reclining, sitting quietly, typing, and walking around. Clothing insulation varied between 0.27 clo and 1.12 clo, with

Table 3 Statistical summary of indoor thermal conditions and thermal sensation vote according to study location

Location	Variable	T_o (°C)	T_a (°C)	T_g (°C)	T_{op} (°C)	*RH* (%)	V_a (m/s)	*TSV*	T_c (°C)
Kuala Lumpur (*N*=467)	Mean	30.4	23.6	23.8	23.8	59.4	0.20	-0.5	24.7
	S.D.	2.2	2.5	2.3	2.3	6.5	0.11	1.2	2.1
	Minimum	23.2	17.5	18.0	18.0	45	0.02	-3	15.6
	Maximum	34.9	28.6	28.6	28.6	80	0.73	2	31.4
Shah Alam (*N*=161)	Mean	29.6	23.1	23.3	23.3	65.9	0.19	-0.5	24.3
	S.D.	2.1	1.5	1.5	1.5	6.0	0.13	1.1	2.0
	Minimum	23.5	18.7	18.5	18.5	49	0.02	-3	19.5
	Maximum	34.5	26.0	26.2	26.2	81	0.66	2	29.5

Note: *N*: Number of responses; S.D.: Standard deviation; T_o: Outdoor air temperature; T_a: Indoor air temperature; T_g: Indoor globe temperature; T_{op}: Indoor operative temperature; *RH*: Indoor relative humidity; V_a: Indoor air velocity; *TSV*: Thermal sensation vote.

Table 4 Statistical summary of personal parameters based on the location of study

Location	Variable	Age (years)	Height (m)	Weight (kg)	*BMI* (kg/m^2)	A_D (m^2)	Clothing insulation (clo)	Metabolic rate (met)
Kuala Lumpur (*N*=467)	Mean	29	1.65	66.4	24.4	1.72	0.57	1.1
	S.D.	6	0.09	14.7	4.3	0.20	0.17	0.2
	Minimum	20	1.51	49.0	16.3	1.46	0.27	0.8
	Maximum	49	1.87	108.0	37.2	2.33	1.12	1.7
Shah Alam (*N*=161)	Mean	36	1.64	59.8	22.1	1.64	0.62	1.1
	S.D.	5	0.06	8.84	2.3	0.14	0.13	0.1
	Minimum	27	1.56	45.0	17.1	1.45	0.45	0.8
	Maximum	43	1.76	78.0	25.2	1.94	1.10	1.7

Note: *N*: Number of responses; S.D.: Standard deviation; BMI: Body Mass Index; A_D: Body surface area.

mean values slightly higher in Shah Alam at 0.62 clo compared to 0.27 clo in Kuala Lumpur.

3.2 Effects of personal characteristics on thermal comfort

The descriptive summary in Table 5 shows mean values of comfort temperature and thermal perceptions of respondent characteristics (gender, age, *BMI* and body surface area). The one-way ANOVA analysis on *BMI* with comfort temperature showed a statistically significant link between groups (F(3,624) = 8.34, $p<0.001$). The post hoc test showed underweight group had 1.2 °C higher comfort temperature compared to obese group ($p=0.11$). Those with normal BMI also had lower comfort temperature at 24.5 °C in comparison with those in overweight group (25.3 °C). The results could indicate that a greater *BMI* is associated with a lower mean comfort temperature (see Fig. 1).

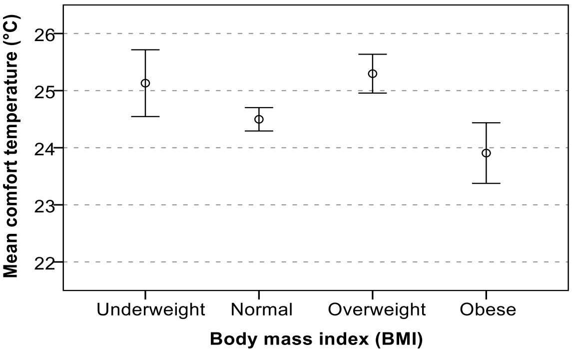

Fig. 1. Mean comfort temperature in each *BMI* category with 95% confidence interval (mean ±2 S.E).

An adult's bodily surface area is typically 1.7 m^2. In line with *BMI*, this study indicated that participants with below-average surface areas have a significantly higher comfort temperature (24.9 °C) than those who are above-average (24.3 °C), $t(626)=10.07$, $p<0.001$ (see Fig. 2). The relationship between anthropometrics (*BMI* and A_D) and thermal comfort in this study is consistent with studies by Rupp *et al.* [16], Maykot *et al.* [15], and Indraganti and Humphreys [21]. In contrast to their findings, this study revealed no effect of gender on comfort temperature.

The subjective reactions are naturally linked to the thermal environment. This study explores the impact of personal characteristics on the subjective reactions obtained from the thermal comfort questionnaire. There were no statistically significant correlations between the thermal sensation vote (*TSV*) and individual traits. Based on one-way ANOVA, *BMI* has some influence on thermal preference (*TP*) [F(3,624) = 3.42, $p = 0.017$].

With mean thermal preference values of 0.3 and 0.2, respectively, the difference in thermal preference between underweight and obese *BMI* groups was particularly pronounced, showing a tendency for those with lower *BMI*s to favour warmer environments. Similarly, significant difference was found between normal and obese group. The results diverge from a study conducted in subtropical Brazil by Rupp *et al.* [16]. Despite having lower comfort temperatures than respondents with normal or underweight *BMI*, the investigators found that overweight respondents preferred warmer environments.

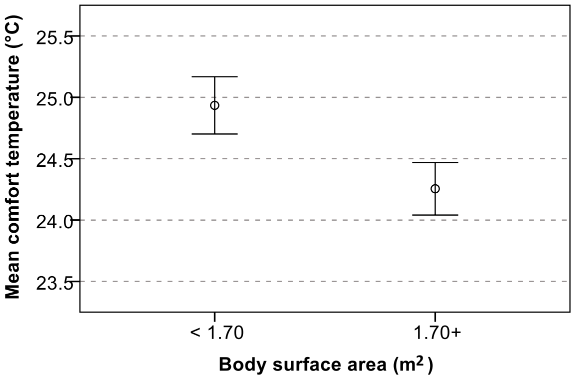

Fig. 2. Mean comfort temperature of below and above average body surface area with 95% confidence interval (mean ±2 S.E).

Table 5. Descriptive statistics of respondent characteristics on comfort temperature and subjective votes

Personal characteristics		*N*	*T*$_c$ (°C)		*TSV*		*TP*		*OC*	
			Mean	***S.D.***	**Mean**	***S.D.***	**Mean**	***S.D.***	**Mean**	***S.D.***
Gender	Female	380	24.6	2.08	−0.4	1.19	0.1	0.98	4.0	1.30
	Male	248	24.6	2.07	−0.6	1.13	0.1	0.89	4.2	1.32
Age	< 30 years	297	24.8	2.07	−0.5	1.15	0.1	0.98	4.2	1.29
	> 30 years	331	24.5	2.07	−0.4	1.19	0.1	0.92	4.0	1.32
BMI	Underweight (<18.5)	46	25.1	1.97	−0.6	1.22	0.3	0.96	3.7	1.18
	Normal (18.5 – 24)	401	24.5	2.08	−0.5	1.16	0.1	0.93	4.2	1.31
	Overweight (25 – 30)	117	25.3	1.86	−0.6	1.15	0.1	0.85	4.2	1.27
	Obese (>30)	64	23.9	2.12	−0.2	1.24	−0.2	1.12	3.7	1.40
A_D	< 1.7 m^2	349	24.9	2.22	−0.5	1.21	0.1	0.94	4.1	1.32
	> 1.7 m^2	279	24.3	1.82	−0.4	1.13	0.1	0.95	4.0	1.30

Notes: *N*: Number of data; *S.D.*: Standard deviation; *BMI*: Body Mass Index; A_D: Dubois' body surface area; T_c: Griffiths' comfort temperature; *TSV*: Thermal sensation vote; *TP*: Thermal preference; *OC*: Overall comfort.

3.3 Effects of office characteristics on thermal comfort

3.3.1 Office occupancy and size

Based on the descriptive summary in Table 6, offices with a single occupant had the highest mean comfort temperature at 25.0 °C; followed by offices with two to four occupants, it was 24.8 °C; and in offices with five or more, it was 24.1 °C. One-way ANOVA analysis showed the relationship between room occupancy groups were statistically significant with comfort temperature (F(3,624)=5.109, $p=0.002$). The differences were significant between private offices and offices with 5 to 6 persons ($p=0.005$) and between 2 to 4 persons with 5 to 6 persons ($p=0.01$). The lower comfort temperature in multi-occupant offices (see Fig. 3) could be caused by the heat that was radiated from the numerous people within. The lower comfort temperature in multi-occupant offices indirectly agrees with a study that found a higher energy demand during working hours with high occupancy [37]. Moreover, thermal preference in private office was significantly higher than offices with more than seven occupants ($p=0.026$), implying warmer preference in multi occupied offices.

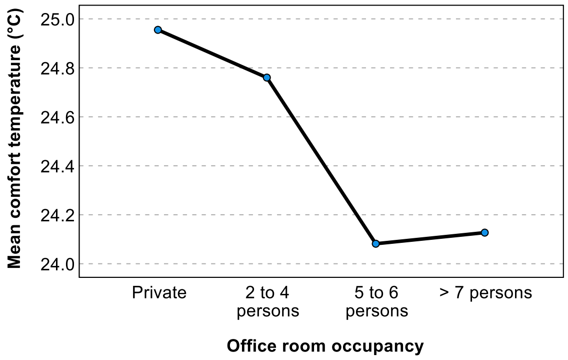

Fig. 3. One-way ANOVA means plots of comfort temperature and office room occupancy

Additionally, office room size had a significant relationship with comfort temperature (F(2,625)=9.66, p<0.001). The difference was significant between offices smaller than 40 m^2 (24.7 °C) and offices larger than 80 m^2 (23.7 °C), varying by one degree Celsius (p<0.001). Correspondingly, thermal preference was statistically significant ($p<0.05$) with larger offices having an inclination to warmer preference. Based on observation, larger offices did have higher number of occupants presents during field measurement, which would explain the identical findings between room occupancy and office sizes.

3.3.2 Internal shading device and floor finishing

Vertical venetian and roller blinds were used as shading mechanisms in the examined offices. Office spaces without shading devices were adjacent to the building's interior corridors and did not face the outdoors directly. The absence of shading device were compared with both window blinds and the one-way ANOVA results was significant between groups (F(2,625)=9.11, $p<0.001$). Rooms without shading devices had mean comfort temperature that were higher (25.3 °C) than rooms with roller blinds (24.3 °C), $p<0.001$, whereas rooms with roller blinds had somewhat lower mean comfort temperature than rooms with vertical blinds ($p=0.009$). However, no significant relationship was found between vertical blinds and the lack of shading device.

In this study, offices with tiled floors had a significantly higher mean comfort temperature at 25.1 °C compared with wool carpeting at 24.4 °C ($p<0.001$). The findings imply a psychological adaptation that wool carpets might offer extra warmth, resulting in a lower comfort temperature. Further analysis with thermal sensation votes supported the preceding statement with a significant result between rooms with tiled floorings and wool carpets ($p=0.047$). Occupants felt much cooler in offices with tiles ($TSV=-0.6$) than with wool carpets

Table 6. Descriptive statistics of office design characteristics on Griffiths' comfort temperature and subjective votes

Office design characteristics		*N*	T_c (°C)		*TSV*		*TP*		*OC*	
			Mean	*S.D.*	Mean	*S.D.*	Mean	*S.D.*	Mean	*S.D.*
Type of office	Private	127	25.0	2.16	−0.5	1.24	0.1	0.87	4.2	1.19
	2-4 persons	344	24.8	2.04	−0.5	1.20	−0.1	0.97	4.1	1.34
	5-6 persons	120	24.1	2.07	−0.3	1.10	0.0	1.00	4.0	1.41
	> 7 persons	37	24.1	1.78	−0.6	0.79	−0.4	0.69	3.9	0.99
Office size	< 40 m^2	297	24.7	2.14	−0.4	1.18	0.0	0.88	4.2	1.23
	40-79 m^2	245	24.9	2.07	−0.5	1.28	0.0	1.04	4.1	1.37
	> 80 m^2	86	23.7	1.60	−0.4	0.74	−0.3	0.88	3.8	1.28
Shading device	No	78	25.3	1.95	−0.4	0.88	−0.2	0.79	4.4	1.13
	Vertical blinds	289	24.8	2.09	−0.5	1.30	−0.1	0.99	4.1	1.33
	Roller blinds	261	24.3	2.03	−0.4	1.11	0.0	0.94	4.0	1.32
State of blinds	Open	256	25.1	1.98	−0.3	1.19	0.0	0.98	4.2	1.28
	Close	372	24.3	2.13	−0.6	1.13	−0.2	0.89	4.0	1.34
Floor finishing	Tiles	227	25.1	2.15	−0.6	1.08	−0.2	0.83	4.3	1.26
	Wool carpet	373	24.4	1.97	−0.4	1.21	−0.1	1.01	4.0	1.34
	Wood	28	24.5	2.29	−0.4	1.29	0.5	0.74	4.2	1.09

Notes: *N*: Number of data; *S.D.*: Standard deviation; T_c: Griffiths' comfort temperature; *TSV*: Thermal sensation vote; *TP*: Thermal preference; *OC*: Overall comfort.

(*TSV*=−0.4) though no significant relationship was found with thermal preference between the two groups. The overall comfort, however, was significant between tiled floorings and wool carpet at *p*=0.023. Offices with tiled flooring had higher overall comfort rating in comparison to offices with wool carpets.

3.3.3 State of blinds

During the field study, the mean comfort temperature was noticeably higher with the blinds open (25.1 °C) than when they were closed (24.3 °C), *t*(626)=0.748, *p*<0.001. The higher comfort temperature found when blinds open is comparable to a Japanese study on window-opening behaviour during summer in residential buildings [35].

A European study by Nicol *et al.* [38] found that the use of blinds were integral to adjust light levels presumably for occupants satisfaction. The absence of solar radiation from the blinded windows could cause the comfort temperature to drop. The thermal sensation vote (*TSV)* was significant only with the opening and closing of blinds. Even though the mean *TSV* was in the cold spectrum (negative values), occupants voted for a slightly cooler sensation (−0.6) when the blinds were closed compared to when blinds were open (−0.3), which was closer to the neutral feeling (*TSV* = 0).

The binomial logistic regression was computed by categorizing the opening of blinds behaviour into binary data, 0 for closed blinds and 1 for opened blinds. The relationship between blind opening behaviour was analyzed with indoor operative temperature (T_{op}), and outdoor air temperature (T_o). The relationships were significant with all temperature predictors and are described in Equations 7 and 8.

$$\text{logit (P)} = 0.289T_{op} - 7.266\ (N{=}628,\ R^2{=}0.08,\ S.E.{=}0.043,\ p{<}0.001) \quad (7)$$

$$\text{logit (P)} = 0.181T_{o} - 5.867\ (N{=}628,\ R^2{=}0.03,\ S.E.{=}0.040,\ p{<}0.001) \quad (8)$$

where *N* is the number of data, R^2 is Cox and Snell R^2, *S.E.* is the standard error of the regression coefficient, and *p* is the significance level of the regression coefficient. The logistic regression curves are illustrated in Fig. 4. The proportion of blinds open is exponential to all temperature predictors. The regression coefficient for indoor operative temperature was 0.289, and at 30 °C, the proportion of blinds being opened is 0.8, similar to that of previous studies [35, 39].

In window-opening behaviour studies, occupants' resort to opening windows to improve ventilation. In Fig. 4, the proportion of blinds open increases with the rising outdoor air temperature, in accordance to study by Nicol *et al.* [38], which found smaller proportion of closed blinds during summer months compared to winter. During the field study, the windows were closed; thus, the adaptive method of opening the blinds was due to feeling cooler and wanting slightly warmer thermal conditions. As seen in Table 6, the mean thermal sensation vote when the blinds were open was −0.3, while when the blinds were closed, the mean value was −0.6, which was much cooler. Concurrently, the mean thermal preference during closed blinds was −0.2, indicating a slightly warmer preference than 0 (no change) when the blinds were opened.

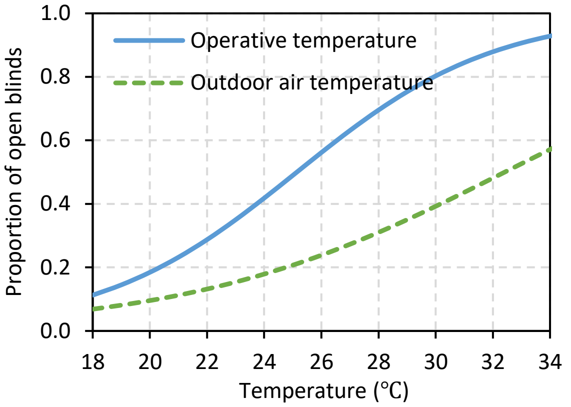

Fig. 4. Correlation between the proportion of opening blinds and temperatures.

4 Conclusions

This study analyzed comfort temperature and subjective reactions using t-test and one-way ANOVA to determine the impact of personal and building characteristics on thermal comfort. Our findings are as follows:

1) Respondents with higher *BMI* and larger than average body surface area (A_D>1.7 m^2) had substantially lower comfort temperatures.
2) Respondents with lower *BMI* preferred warmer environments, while normal and overweight BMIs rated their overall comfort higher than those underweight or obese.
3) Most single-occupant respondents preferred a cooler environment, while those sharing office areas preferred a warmer or no change in their thermal environment.
4) An increase in mean comfort temperature was linked to the absence of window blinds that provided shading.
5) Occupants felt slightly cooler when the blinds were closed (*TSV* = −0.6) than when the blinds were opened (*TSV* = −0.3)
6) Opening the window blinds resulted in a higher comfort temperature and a less cold environment, and vice versa.
7) As the outdoor air temperature and indoor operative temperature increases, the proportion of opening the blinds increases.

It can be summarized that the body mass index was significant to comfort temperature. Therefore, assigned positioning based on occupants' BMI and thermal preference could maximize thermal comfort. In addition, as the role of window blinds helps alleviate cooler feelings among occupants in air-conditioned office rooms, it is suggested that internal window blinds be an essential tool in sustainable design for adaptive thermal comfort indoors.

5 Limitations of research

The scope of this study is limited to urban AC-operated field research, the average daytime outside air temperature ranged from 23 to 35 °C. Consequently, this study's conclusions may not apply to various ventilated buildings and climates. Additionally, this research was conducted in universities comprising staff and students. Thus, the demographics were rudimentary to occupants in the education industry. Metabolic rate and clothing insulation were not measured but were estimated using ASHRAE Standard 55 [25] as a reference. The office design parameters included in this study were not assessed on their material specifications and thermal properties. The analysis of shading devices, glazing ratio, and floor finishings was solely based on physical categorization.

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