Assessment of Overheating Risk in School Classrooms at Hot-Humid Climate

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Assessment of Overheating Risk in School Classrooms at Hot-Humid Climate

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Abstract: *Students in naturally ventilated school classrooms are exposed to warmer conditions for extended periods due to intensified heat waves brought on by global warming. This study aims to investigate thermal comfort and assess the overheating risk in three secondary schools in Malaysia. Four classrooms, which consist of students aged 13 to 16 years, were selected, and the thermal environments were measured for one day at each school, simultaneously with questionnaire surveys. Indoor air temperature was found to be higher than the outdoor temperature. A comfort temperature of 29.6 °C was obtained from the Griffiths method, and when feeling a neutral sensation, students much prefer cooler environments. All classrooms exceed the overheating fixed threshold temperature of 28.0 °C at a proportion of less than 13%. Based on the adaptive overheating criteria, the overheating risk was only 2%, indicating no overheating and minimal discomfort. This study provides insight into the overheating scenario in typical school classrooms in a hot-humid climate.*

Keywords: thermal comfort; overheating; school classrooms.

1. INTRODUCTION

Children spend considerable time in classrooms and must acclimatize to the thermal environment with minimal adaptive opportunities compared to other built environment settings [1]. The adaptive opportunities for students in classrooms were limited to clothing, window openings, and operating ceiling fans [2]. Under natural ventilation, comfort temperatures and ranges in school settings were higher and broader compared to existing standards [3], and differences in thermal perception can also be observed between students in schools and universities [4].

Overheating in a classroom result from heat buildup from solar radiation, internal sources such as occupants, and information communication technology (ICT) equipment [5]. Students may feel overheated quickly if no adaptive behaviors (i.e., environmental and personal) are practiced [6]. In warmer environments, such as when the indoor temperature rises above 28 °C, students' classroom performance falls below 80% [7].

Due to Malaysia's climate, students in naturally ventilated classrooms were constantly subjected to warm conditions. The level one heatwave (outdoor temperature between 35.0 °C to 37.0 °C recorded for at least three consecutive days), which occurred in mid-2023, prompted the suspension of outdoor school activities [8]. Thus, the classroom ought to be able to offer comfort and reduce heat stress. This study aims to investigate thermal comfort in existing classroom conditions and assess the likelihood of overheating risk based on temperature threshold for secondary schools in Malaysia.

2. METHODS

2.1 Outdoor Climate

The climate in Malaysia is characterized by hot and humid (A_f) throughout the year, with the average outdoor air temperature for the previous 30 years (1991-2020) being 27.2 °C [9]. The average daily temperature increases at 0.2 °C every ten years, indicating a gradual warming trend. The weather was influenced by two main "monsoons" or seasons, with most rainy days falling between November and March and drier days occurring between May and September [10].

2.2 Description of Selected Schools and Classrooms

The field study was conducted in three secondary schools in Malaysia's capital city, Kuala Lumpur (Fig. 1). The school buildings, constructed with reinforced concrete, ranged in height from two to tenth floors. Four classrooms were selected in each school, occupied by students aged 13 to 16. The floor area varied between 60 and 108 m², with a glazing ratio of around 0.13 to 0.47. Generally, classrooms were ventilated through natural ventilation and fans (i.e., ceiling and wall fans).

Fig. 1. Building façade of (a) School A, (b) School B, (c) School C, and (d) a typical classroom layout.

2.3 Data Collections

The one-day measurement was carried out in four classrooms per school on randomly selected floors and orientations between February and June 2023, covering rainy and dry weather conditions. A similar method of one-day measurement to estimate overheating and discomfort in classrooms was conducted across eight and four schools during the summer season between 2014/2015 and 2023, respectively [11-12]. In addition to thermal variations, constrained behavioral adaptations for school students also impact overheating [6]. Limited adaptive opportunities in classrooms resulted in different thermal perceptions and the likelihood of overheating from occupants in other indoor settings (i.e., adults in the office) [11].

Therefore, thermal comfort surveys were conducted simultaneously with the measurement to obtain students' perceptions of the classrooms' thermal environment. The contents of the questionnaires were referred from a previous study in university classrooms and office settings in Malaysia [4,13]. Environmental variables (air and globe temperature, relative humidity, and air velocity) were measured to assess classroom thermal comfort and overheating risk. Meanwhile, mean radiant and operative temperature were estimated based on an equation from the standard [14].

The instruments were set up before students' arrival in the morning at two locations, the front and the back of the classrooms, at 1.1 m above the floor [14]. Before commencing the fieldwork, all instruments had been calibrated and verified. Outdoor environments were obtained from a nearby weather station.

2.4 Overheating Criteria

The overheating criteria considered in this study were static (or fixed) threshold temperatures, which do not consider varying ambient temperatures and adaptive threshold temperatures. For fixed criteria, the indoor temperatures shall not exceed 26.0 °C and 28.0 °C for 1% of the annual occupied hours, as adopted in the Chartered Institution of Building Services Engineers (CIBSE) Guide A for bedroom and living rooms, respectively. The latter temperature was also used for office and school buildings [15].

For adaptive criteria, the technical memorandum (TM)52 of CIBSE [16] was used in this study, which was developed based on EN 15251 and ASHRAE 55 (adaptive comfort standards) on the assumption that the risk of building overheat relates to thermal comfort and prevailing outdoor conditions. Using the adaptive equation in EN 15251 [17], the comfort (operative) temperature was estimated, which follows:

$$T_c = 0.33T_{rm} + 18.8 \quad (1)$$

where T_{rm} is the running mean outdoor air temperature (°C). The Category II upper limit was applied to calculate the adaptive threshold temperature:

$$T_{max} = 0.33T_{rm} + 21.8 \quad (2)$$

The percentage of overheating was predicted from the difference between operative and comfort temperature, given by:

$$\Delta T = T_{op} - T_{max} \quad (3)$$

where ΔT is the temperature exceedance in K.
In TM52, the overheating occurred if any two of these criteria shown in Table 1 were exceeded:

Table 1. Criteria of adaptive overheating [16].

	CIBSE TM52 Overheating Criteria
1	The number of hours (H_e) during the operative temperature exceeding the T_{max} shall not exceed 3% of the occupied hours (ΔT≥1).
2	On any day, the sum of the weighted exceedance should be less or equal to 6. $W_e \leq 6$, where: $W_e = \sum h_e \times WF$ and h_e is the time (h).
3	The indoor operative temperature should be less than the T_{max} by 4 °C or more at any time (ΔT≥4).

The adaptive action taken by the students can be an indicator of thermal discomfort [18]. Temperature differences, T_{diff}, were estimated between the indoor operative temperature, T_{op}, and the comfort temperature, T_c, derived from equation (1). $T_{diff} > 3$ is regarded as outside the comfort band due to exceeding Category II of EN 15251 comfort limit [16,19], and the adaptive actions carried out during the temperature variations were regarded as a measure to alleviate the discomfort [6].

Additionally, heat stress can be evaluated based on heat stress indices by estimating wet-bulb globe temperature (WBGT) and universal thermal climate index (UTCI). The WBGT index originated 50 years ago to combat heat illness in army camps [20]. The WBGT for indoors adopted the weighted average of wet bulb temperature (WBT) and globe temperature (GT) based on the following equation:

$$\text{WBGT} = 0.7 \text{ psychrometric WBT} + 0.3 \text{ GT} \quad (4)$$

This study estimated WBT using a psychrometric chart of ASHRAE 55 based on the approximation value of measured dry-bulb (air) temperature and relative humidity [21]. The ranges of WBGT heat stress were divided into five: below 18.0 °C (no danger), between 18.0 and 23.0 °C (caution), between 23.0 and 28.0 °C (extreme caution), between 28.0 and 30.0 °C (danger), and above 30.0 °C (extreme danger) [22].

The derivation of UTCI requires the value of air temperature (°C), mean radiant temperature (°C), air velocity (m/s), and relative humidity (%), formulated as:

$$\text{UTCI} = T_a + \text{Offset}(T_a, T_{mrt}, V_a, RH) \quad (5)$$

where T_a is air temperature, T_{mrt} refers to mean radiant temperature, RH is relative humidity, and V_a is air velocity at 10 m height. For indoor measurement at x m (i.e., 1.1 m) height, the measured air velocity (V_{ax}) can be converted based on the following equation: [23].

$$V_a = V_{ax} \times LOG(10/0.01)/LOG(x/0.01) \quad (6)$$

The estimation was done using an online calculation tool [24]. The ranges of UTCI were: between 9.0 to 26.0 °C (no heat stress), between 26.0 to 32.0 °C (moderate heat stress), between 32.0 to 38.0 °C (strong heat stress), between 38.0 to 46.0 °C (very strong heat stress), and above 46.0 °C (extreme heat stress) [22].

3. RESULTS AND DISCUSSIONS

3.1 Outdoor and Indoor Environments

The average thermal environment that had been monitored and estimated during the one-day measurement for each school is shown in Table 2. The lowest outdoor and indoor temperature was recorded in School A due to cloudy weather in the morning, as indicated by high relative humidity. The average outdoor temperature was above 30 °C in Schools B and C, corresponding to the drier weather season. The wind speed in Kuala Lumpur was generally low, with the average varying between 1.0 to 1.8 m/s.

The recorded indoor air temperatures are higher than the outdoor, showing a 0.6 °C difference at most. Relative humidity varies between 65 to 75%, and air velocity ranges by 0.2 to 0.4 m/s. Among the thermal indices, indoor air temperatures were the highest, while the average of the globe and operative temperatures were almost similar. The mean radiant temperatures were the lowest among the other. Regardless, the relationship was significant ($p < 0.05$), and in this study, the operative temperatures (T_{op}) were used for further analysis.

3.2 Thermal Comfort

The actual mean thermal sensation votes (*TSV*) and predicted mean votes (*PMV*) were plotted for linear regression analysis, as shown in Fig. 2(a) and Fig. 2(b). The regression model for the *TSV* was significant (R^2=0.28, $p < 0.05$). For *PMV*, the regression model of the entire data set is statistically significant (R^2=0.94, $p < 0.001$). The temperature required to change one scale unit is similar for *TSV* (1/0.32=3.1 °C) and *PMV* (1/0.28=3.6 °C). The estimated comfort temperatures were 23.9 °C and 29.5 °C based on the PMV and TSV regression equations. Hamzah et al. [24] found similar comfort temperatures for secondary school classrooms in Indonesia based on regression analysis of *PMV* and *TSV*. However, the bias in *PMV* prediction was influenced by the prevailing outdoor environment, and thus, it is not reliable for buildings subjected to warmer conditions [25]. Jindal [26] obtained a gentle slope of the *TSV* line compared to the steep slope of *PMV*, which shows students' adaptation to the warm climate in India.

For comparison, the comfort temperature was also estimated using Griffiths method by the following equation:

$$T_c = T_{op} + \frac{(0\text{-}TSV)}{\alpha} \quad (7)$$

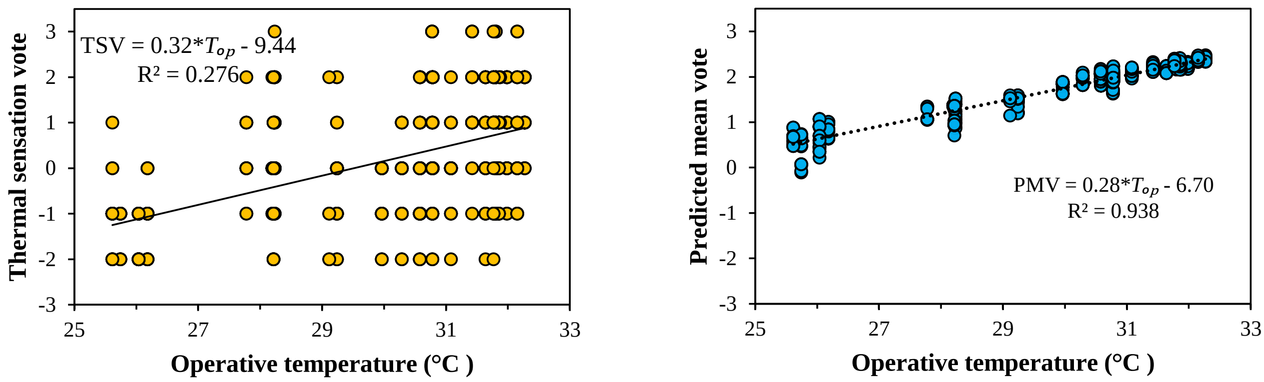
where 0 indicates "neutral" in the seven-point sensation scale, *TSV* is the thermal sensation vote obtained from the questionnaire surveys, and α is Griffiths' constant taken at 0.50 as per previous studies [13][27]. The comfort temperature was 29.6 °C based on the 522 datasets (Table 3). Accordingly, the mean operative (comfort) temperatures were also compared based on thermal sensation, preference, and overall comfort votes. The comfort temperatures were almost similar, with the highest at 30.2 °C, when around 30% of students voted "neutral".

The thermal preferences of students for thermal sensation votes are shown in Fig. 3. Since students do not vote for -3 (very cold) for *TSV*, only the scales from -2 (cold) to 3 (very hot) were analyzed. Within the central comfort band (-1 to 1), more than 60% of students voted preference for cool environments. Warm conditions were least desirable; overall, students voted less than 20%. When the neutral temperature was high, occupants preferred a lower temperature and vice versa to ensure their comfort [28].

Table 2. Descriptive statistics of outdoor and indoor thermal environments.

School	Classroom	Var.	Outdoor			Indoor					
			T_o (°C)	RH_o (%)	V_o (m/s)	T_a (°C)	T_g (°C)	T_{op} (°C)	T_{mrt} (°C)	RH (%)	V_a (m/s)
A	C1 - C4	Mean	27.0	85	1.0	27.2	27.1	27.0	26.8	75	0.2
		SD.	2.4	11	0.5	1.4	1.5	1.5	1.6	7	0.1
B	C5 - C8	Mean	30.6	76	1.5	30.6	30.4	30.3	29.9	66	0.4
		SD.	1.9	8	0.8	1.2	1.2	1.2	1.2	6	0.1
C	C9 - C12	Mean	30.5	80	1.8	31.1	30.9	30.9	30.7	68	0.3
		SD.	1.8	9	1.0	0.6	0.6	0.7	0.7	4	0.1

Note: Classroom 1 to 4, and so on; *SD.*: standard deviation; T_o: Outdoor air temperature, RH_o: Outdoor relative humidity, V_o: Outdoor wind speed; T_a: Indoor air temperature; T_g: Indoor globe temperature; T_{op}: Indoor operative temperature; T_{mrt}: Indoor mean radiant temperature; *RH*: Indoor relative humidity; V_a: Indoor air velocity.



(a) (b)

Fig. 2. Regression of (a) actual *TSV* and (b) *PMV* to operative temperature.

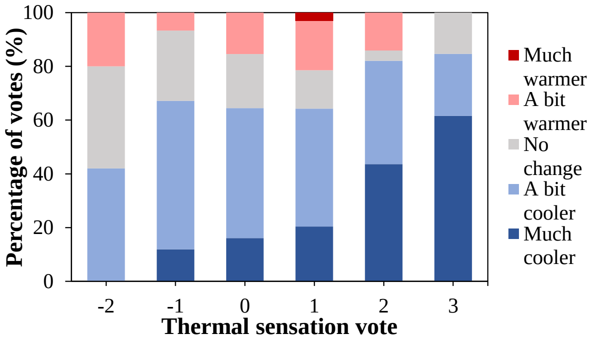


Fig. 3. Cross-tabulation of thermal preferences and thermal sensation votes.

Table 3. Comfort temperatures based on Griffiths method and questionnaire survey votes.

Method	N_s	T_c (°C)
Griffiths (α = 0.50)	522	29.6
TSV (0 “neutral”)	149	30.2
TP (0 “no change”)	103	29.5
OC (5 “moderately comfortable” & 6 “very comfortable”)	167	29.0

Note: N_s: Number of samples; T_c: Comfort temperature; *TSV*: Thermal sensation vote; *TP*: Thermal preference; *OC*: Overall comfort.

3.3 Overheating Assessments

Three operative temperature ranges for the fixed criteria were applied: below 26.0 °C, between 26.0 to 28.0 °C, and above 28.0 °C. The percentage of operative temperatures at the given ranges for each classroom is shown in Fig. 4. School A had a wider temperature range, with the highest at 39% in C3 at temperatures below 26.0 °C. School B exceeded the fixed temperature threshold most of the time at 12%, while School C exceeded the fixed temperature threshold at all times around 10%. Comparing the building factors, School C had no overhang to provide shading for the external windows. The windows are also arranged for side ventilation, unlike the other school classrooms, which adopted cross ventilation. In School B, only C8 exceeded the temperature threshold at all times. It can be due to no windows or doors being opened during occupied hours, contributing to airtightness. Newer school buildings in the UK with higher airtightness led to a quick rise in overheating [11,29]. Besides, almost all students had laptops, hence further exacerbating the heat in classroom C8.

In Fig. 5, the discomfort percentages were obtained from the difference between operative and comfort temperatures and compared to the TM52 criteria to assess the overheating risk. The likelihood of overheating was about 2% when there was no difference between the operative and comfort temperature. Based on criterion 1, the number of hours for ΔT≥1 was less than 3% of the occupied hours. Furthermore, the difference between indoor operative and comfort temperatures does not reach 4 K (criterion 3). Hence, as two of the criteria do not exceed the overheating criteria from the standard, the overheating risk for the investigated school classrooms was minimal.

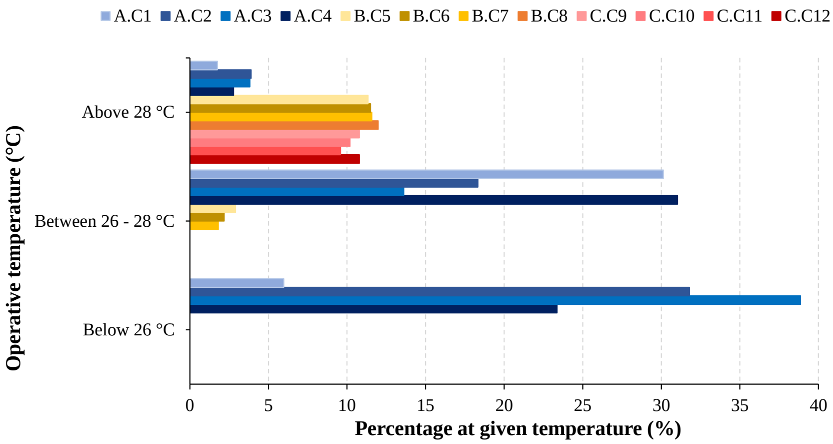


Fig. 4. Proportion of operative temperature for each classroom at fixed temperature ranges.

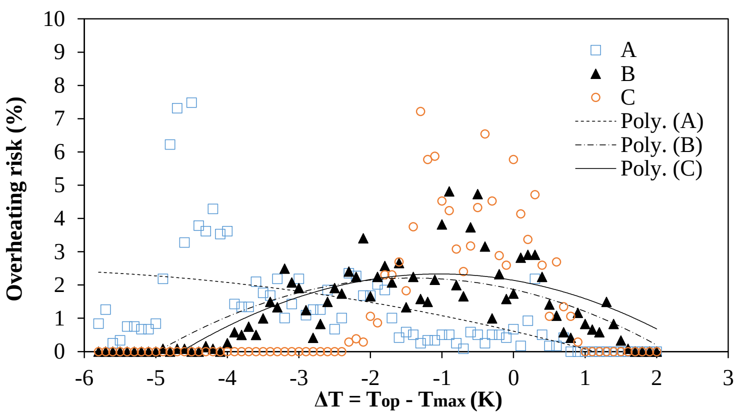


Fig. 5. Discomfort due to overheating in each school.

As shown in Fig. 6 and Table 4, when discomfort arises ($T_{diff} > 3$) nearly half of the students took personal adaptive actions. The frequency of removing the layer of clothing is highest (60%), followed by fanning themselves (52%), rinsing their face and hands (51%), and drinking something cold (46%). Doing nothing and drinking something warm was prevalent when ($T_{diff} < 0$), as temperature variations were within the comfort band. There was an instance when ($T_{diff} > 4$), exceeding the upper zone of EN 15251 Category III building, and 13% of students removed the clothing layer. Similar to the previous studies, clothing behavior was frequently applied when the temperature variations were higher (i.e., overheating) compared to fanning and drinking actions [6,30].

3.4 Heat Stress

A comparison between the heat stress indices is shown in Table 5. Based on the WBGT mean value, School B and School C were at risk of falling into the "danger" zone compared to School A, as the temperatures almost reached 28.0 °C. Meanwhile, based on the mean UTCI estimated for each classroom, school A falls in "moderate" heat stress, while school B falls in both "moderate" and "strong" heat stress, and school C falls in "strong" heat stress. The result suggests the potential for heat stress occurrence in the classrooms.

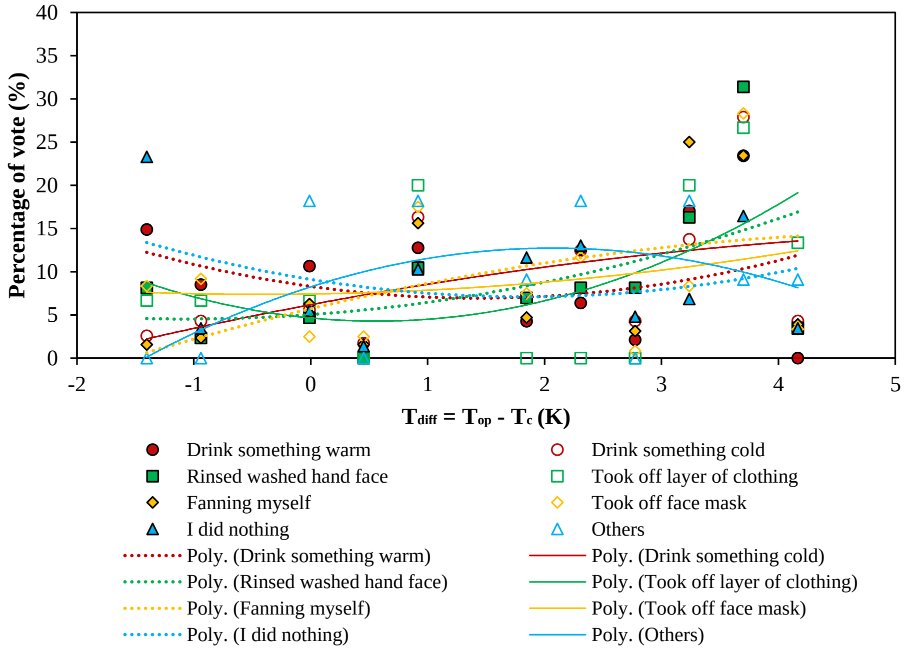


Fig. 6. Personal adaptive behaviors against the T_{diff} (K).

Table 4. Percentage of students doing personal adaptive behaviors within the T_{diff} (K).

Adaptive behaviors	Percentage of adaptive behaviors (%)					
	$T_{diff} < 0$	$0 < T_{diff} < 1$	$1 < T_{diff} < 2$	$2 < T_{diff} < 3$	$3 < T_{diff} < 4$	$T_{diff} > 4$
Drink something warm	34	13	4	9	40	1
Drink something cold	12	18	7	17	42	4
Rinsed face and hands	15	10	7	16	48	3
Took off a layer of clothing	20	20	1	2	47	13
Fanning myself	10	17	5	16	48	4
Took off face mask	20	20	8	13	37	3
I did nothing	32	12	12	18	23	3
Others	18	18	9	18	27	9

Note: T_{diff}: Temperature difference (K).

Table 5. Comparison between heat stress indices.

School	Classroom	Mean WBGT (°C)	Perception	Mean UTCI (°C)	Perception
A	C1	24.7	Extreme caution (23.0 to 28.0 °C)	29.4	Moderate heat stress (26.0 to 32.0 °C)
	C2	25.0		30.3	
	C3	24.9		30.3	
	C4	24.7		29.4	
B	C5	26.6	Extreme caution	31.9	Moderate heat stress
	C6	27.1		33.2	Strong heat stress (32.0 to 38.0 °C)
	C7	27.0		32.7	
	C8	27.0		33.4	
C	C9	27.7	Extreme caution	34.2	Strong heat stress
	C10	27.8		33.8	
	C11	27.7		33.8	
	C12	27.3		33.4	

Note: Classroom 1 to 12; WBGT: Wet-bulb globe temperature; UTCI: Universal thermal climate index.

4. CONCLUSIONS

This paper evaluates thermal comfort and overheating risk in existing secondary school classrooms. It was found that the indoor air temperatures were higher than the outdoor temperatures, with the difference around 0.6 °C. Using the Griffiths method, the comfort temperature was found to be 29.6 °C, while the *TSV* regression analysis found a similar value of 29.5 °C. In "neutral" sensation, students mostly preferred cooler environments. All classrooms exceed the overheating fixed temperature threshold (i.e., 28 °C) by less than 13%, especially classrooms with inappropriate ventilation conditions (i.e., side ventilation, no openings). Furthermore, it was found that none of the classrooms exceeded the adaptive overheating criteria, indicating no overheating and minimal discomfort. The prevalent personal adaptive behaviors when students experience thermal discomfort were found to be taking off the layer of cloth, followed by fanning themselves and rinsing their faces and hands, and drinking something cold. Although there are limited measurement periods, the findings on overheating can be extended to a similar climate of classroom settings.

5. ACKNOWLEDGEMENT

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