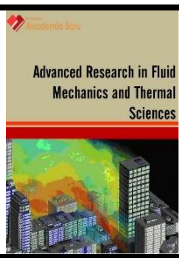
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Pilot Study on Occupants' Thermal Sensation at Different Ambient Temperature in Postgraduate Office with Cooling Mode in University Campus

Open Access

Noor Syazwanee Md Taib[1], Sheikh Ahmad Zaki Shaikh Salim[1*], Aya Hagishima[2], Waqas Khalid[3], Fitri Yakub[1], Nurul Izzati Kamaruddin[1]

[1] Wind Engineering for (Urban, Artificial, Man-made) Environment Laboratory, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia Kuala Lumpur International Campus, Jalan Sultan Yahya Petra 54100 Kuala Lumpur, Malaysia
[2] Department of Energy and Environmental Engineering, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, 6-1 Kasuga Koen, Kasuga, Fukuoka 816-8580, Japan
[3] Department of Mechanical Engineering, School of Mechanical and Manufacturing Engineering, National University of Sciences and Technology (NUST), Islamabad, Pakistan

ARTICLE INFO

Article history:
Received 16 December 2019
Received in revised form 9 August 2020
Accepted 10 August 2020
Available online 4 December 2020

ABSTRACT

With rapid urbanization, massive amount of energy is required to compensate the electricity usage thus calls for a need to Malaysian government issuing standard MS1525:2014 for temperature settings in office buildings to meet energy efficiency goal. In co-sharing spaces, personal thermal comfort is often not met due to the different thermal sensation at different location inside office rooms. This study was conducted at four postgraduate office spaces with cooling mode in university campus located at Kuala Lumpur to evaluate the occupant's thermal sensation. We used different set-point temperature of air conditioning ranging from 18.0°C to 28.6°C. The indoor thermal variables such as air temperature, globe temperature, relative humidity, and air velocity are measured at each respondent's workspace and 200 responses were recorded from ten subjects. The mean value of thermal sensations votes is -0.4 and were within comfort range. 76% of responses voted 'neutral' humidity sensation as occupants have adapted to humid condition in Malaysia. The comfort operative temperature found in this study is 24.9°C which indicates that the minimum recommended temperature for energy conservation did not deprive occupants from comfort.

Keywords:
Thermal comfort; office rooms; set-point temperature

1. Introduction

Heating, ventilation and air-conditioning (HVAC) system consumes majority of energy in building of approximately 40% [1]. As urbanization are rapidly arising, thermal properties of land are

* *Corresponding author.*
E-mail address: sheikh.kl@utm.my

https://doi.org/10.37934/arfmts.78.2.111

tempered causing alteration in urban environmental system which leads to Urban Heat Island (UHI) phenomenon [2,3]. The heated environment can cause great discomfort to humans thus buildings with competent thermal system were built to restore comfort of occupants thermally [4]. A review study shows that there is 0.5 - 8.5% increase in electricity demand for every one-degree temperature rise which is equivalent to 21 (±10.4) Watts per person [5]. A study in an office building in the Philippines discovered 1.4% of cooling energy costs were saved when raising the temperature setting from 22 °C to 24 °C [6] while another study estimated 29% of cooling energy savings when set-point temperature was increased by 2.8 °C [7]. Consequently, the range of indoor parameters are regulated by standards to guide how cooling energy is used in buildings.

Retaining comfort is paramount for the well-being of humans and improved productivity. Standards have been set to specify acceptable range of thermal parameters in indoor environments and although standards are met, not all occupants are thermally satisfied due to different preferences and other potential factors which may not be managed by standards [8]. Studies on thermal comfort are widely done in Europe and United States making the thermal comfort standards from those regions prominent in thermal comfort studies [9-11]. A report done by State of the Tropics in 2014 claimed that 50% of the world's population will soon live in the tropical region by the year 2050 [12] which simultaneously sees the growing number of thermal comfort studies in predominantly hot and humid countries [5-7,13-15] though thermal comfort studies in the tropics is still considered not plenty [16].

Standards for non-residential buildings in hot and humid countries such as Malaysia [17] and Singapore [18] recommended that operative temperature indoors to be within 24°C to 26°C whilst Indonesia [19] recommends 24°C to 27°C. Study done by Damiati *et al.,* [13] in office buildings found that 80% acceptable operative temperature in cooling mode in Kuala Lumpur and Shah Alam, Malaysia is within 24.5°C to 30°C while mixed mode ventilation in Bandung, Indonesia ranges between 26°C and 28°C which is higher than the recommended standards. Han *et al.,* [20] conducted study in hot and humid climate in central southern China discovered operative temperature of 22.0°C to 25.9°C were considered acceptable by 90% occupants. In a hot summer cold winter climate in Changsha, China, upper limit of operative temperature of 29.4°C met 80% satisfaction of occupants [21]. These studies were done in occupant-controlled conditions where higher satisfactory rate is to be the expected outcome. Studies done in environmentally controlled conditions were typically conducted in climatic chambers [22,23] where there was little adaptation of actual office conditions. A Kuala Lumpur study in 2017 considered the different thermostat temperatures in finding occupants' thermal satisfaction and observed the ambient temperature at thermostat settings at 20°C, 24°C and 28°C. The study found that at 20°C set-point, ambient temperature was recorded at an average of 24.6°C whilst at 24°C and 28°C set-point, ambient temperature was 25.6°C and 27.5°C respectively. The disparity of set-point and ambient temperature was because of the wide temperature distribution of the location and possible incompetent cooling system of air conditioners. On that account, this study aims to obtain thermal sensation of occupants at controlled ambient temperatures where the cooling system is competent.

2. Methodology

2.1 Description of Study Area

This research takes place from April to September 2019 at a university campus in Kuala Lumpur (3°10'21.3168''N, 101°43'9.3036''E) located in the west peninsular of Malaysia near the equatorial region with tropical rainforest climate. In average, Kuala Lumpur is subjected to maximum temperature of 33°C and 23°C minimum with annual humidity at 80% on average [17]. Four open plan offices in two investigated buildings (A and B) were selected as study location (See Figure 1). All offices are equipped with one or more ceiling mounted split-type air conditioners with good cooling capability and functional windows. Table 1 shows the descriptions of study locations.

Table 1
Description of study location

Building	Office Code	IF/TF	Orientation	Area (m^2)	N_R	N_s
A	KL1	10/10	East	22.9	3	40
	KL2	4/10	East	37.0	2	32
	KL3	5/10	North	56.4	3	48
B	KL4	2/2	Southwest	51.1	5	80

Note: IF; Investigated Floor, TF; Total Floor, N_R; Number of Respondents, N_s; Number of samples

Fig. 1. Investigated offices

2.2 Thermal Measurements

Indoor environmental parameters measured in this study are air velocity (v_a), air temperature (T_a), globe temperature (T_g) and relative humidity (RH). Air temperature, T_a was measured using HHA-3151 and TMC1-HD sensors, A 40 mm black sphere is fixed to another TMC1-HD sensor to measure globe temperature. HOBO data logger internal sensor was used to measure RH while Kanomax 6501-0G with hot wire anemometer probe 6542-2G measures v_a (See Figure 2). Outdoor temperature (T_o) and outdoor humidity (RH_o) were taken from weather station located at rooftop of ten-storey Building A. All instruments were calibrated before conducting field measurements. Indoor measurements were recorded at 10 seconds intervals over 10-20 minutes sampling time after instruments were stable. Instruments were placed at 1.1m height near occupants' work cubicle within 0.3m radius [24] as shown in Figure 3 and 4. Similar setup was conducted in Malaysian offices for thermal comfort field studies by Damiati *et al.,* [13] and Mustapa *et al.,* [25]. Table 2 shows the information of instruments used in this study. Field measurement was conducted from 9:00AM to 12:00PM for morning session and 1:00PM to 6:00PM for afternoon session when offices were occupied.

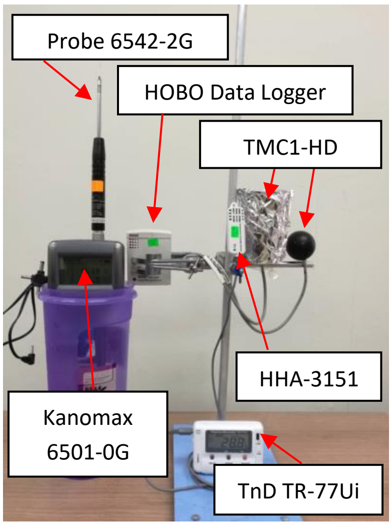


Fig. 2. Equipment setup

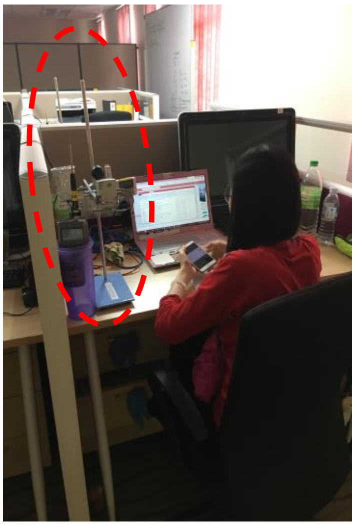


Fig. 3. Field measurement setup. Red dotted circle shows the equipment setup during field measurement

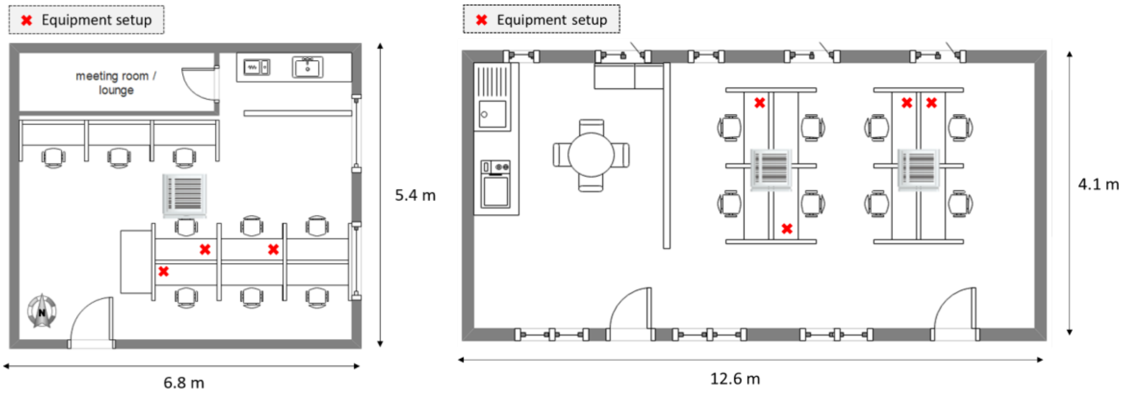


Fig. 4. Field measurement setup in KL3 (left) and KL4 (right)

Table 2
Specifications of instruments used for indoor field measurement

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

2.3 Subjects and Thermal Comfort Survey

Ten postgraduate students between 22 and 30 years old volunteered as subjects in this study consisting of eight females and five males. All subjects have signed consent forms in compliance to Malaysian Personal Data Protection Act 2010. Subjects' information was obtained in the first part of questionnaire. Subjects underwent multiple measurement sessions in the morning and afternoon where each session, as depicted in Figure 5 lasted up to one-hour duration depending on air temperature stability in the room. 200 responses were collected from all subjects.

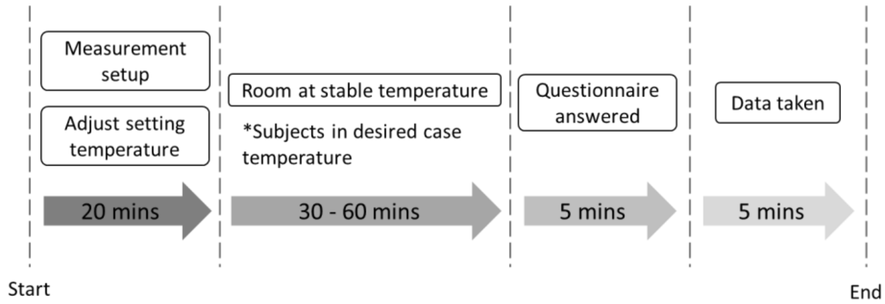


Fig. 5. Field measurement procedure

Questionnaire was split to two parts where the first part includes subjects' demographic and anthropometric information which was filled only once while part two were answered after each field measurement. Part two of questionnaire were distributed online via Whatsapp or email using Google Form after researcher confirmed the temperature indoors has stabilized. The 'right here right now' responses were then recorded. Part two consists of health condition, thermal sensation, preference, activity level and clothing insulation. A revised four-point health assessment scale is adopted from previous study [15] to assure that the response was not influenced by subjects' poor health. The frequently used seven-point thermal sensation vote (TSV) evaluation was taken from The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and modified (mTSV) based on preceding study by Khalid *et al.,* [15] for the reason that warm-hot and cold-cool possibly gives parallel meaning in Malay language. Thermal sensation, preference, air movement vote and overall comfort scale is shown in Table 3.

Table 3
Thermal comfort survey scale

Scale	Thermal Sensation Vote (TSV)	Thermal Preference (TP)	Humidity Sensation (HS)	Humidity Preference (HP)	Air Movement Vote (AMV)	Overall Comfort (OC)
-3	Very cold		Very dry			
-2	Cold	Much cooler	Dry	Much drier		
-1	Slightly cold	A bit cooler	Slightly dry	A bit drier		
0	Neutral	No change	Neutral	No change		
1	Slightly hot	A bit warmer	Slightly humid	A bit humid	No movement	Very uncomfortable
2	Hot	Much warmer	Humid	More humid	Low	Moderately comfortable
3	Very hot		Very humid		Neither high nor low	Slightly uncomfortable
4					High	Slightly comfortable
5						Moderately comfortable
6						Very comfortable

Personal factors of activity level and subjects' clothing were included in the later part two of the survey to estimate the metabolic rate (*met*) and clothing insulation (*clo*) based on ASHRAE Standard 55 2017 [9].

3. Results

3.1 Thermal Environments and Personal Parameters

The personal parameters and thermal environment data were recorded during field measurement at occupants' work spaces and the mean values were obtained as shown in Table 4. T_a and T_g has similar mean values while RH fluctuates with higher deviation compared to other thermal indices. KL1 recorded highest mean T_a of 24.6℃ compared to other study location. Based on observation, the non-airtight glass doors in KL1 could contribute to external heat coming from the corridor although the performance factor of air conditioner cannot be ruled out. Mean values of V_a ranges from 0.14 to 0.29 *m/s* which is acceptable with almost unnoticeable sensation according to Malaysian Standard 2014 [17]. Mean values of clothing insulation and metabolic rate were 0.53*clo* and 1.1*met* respectively which is equivalent to shirt and pants ensemble with sedentary activity.

Additionally, we explored the relation between air temperature, T_a and setting temperature of air conditioner, T_s and noticed that they were significant and highly correlated as portrayed in Table 5. The relation between thermal indexes was also analysed due to multiple thermal indices present in this study. T_a was found to have high correlation with T_g, T_{mrt} and T_{op} as depicted in Table 6 indicating that any of the thermal index can be used in analysis. Ultimately, T_{op} was selected in accordance to previous studies [13,15,25].

Table 4
Thermal environment data and personal parameters

Offices	Item	T_a (°C)	T_g (°C)	T_{mrt} (°C)	T_{op} (°C)	T_o (°C)	RH (%)	RH_o (%)	V_a (m/s)	I_{cl} (clo)	M (met)
KL1	Mean	24.6	24.8	25.2	24.8	30.3	64.8	67.5	0.29	0.59	1.0
(n=40)	S.D.	2.3	2.1	1.8	2.0	2.5	6.5	13.4	0.17	0.19	0.2
	Max.	28.6	28.3	27.9	28.3	33.1	80.1	95.9	0.63	0.94	1.7
	Min.	20.6	21.0	21.7	21.1	24.0	52.5	49.1	0.02	0.30	0.2
KL2	Mean	23.8	24.2	24.7	24.2	31.2	56.8	68.6	0.17	0.60	1.1
(n=32)	S.D.	2.3	2.0	2.1	2.1	1.3	3.1	7.3	0.06	0.11	0.1
	Max.	26.8	26.9	28.0	26.9	33.3	62.0	83.9	0.40	0.96	1.7
	Min.	18.0	18.7	19.6	18.6	29.2	51.6	56.2	0.09	0.30	0.8
KL3	Mean	22.9	23.3	23.7	23.2	30.4	58.1	70.2	0.14	0.58	1.0
(n=48)	S.D.	2.4	2.3	2.2	2.3	1.2	6.7	7.4	0.08	0.10	0.2
	Max.	27.0	27.1	27.3	27.1	32.7	70.9	79.0	0.27	0.79	1.7
	Min.	18.9	19.2	19.7	19.3	28.3	49.1	55.8	0.02	0.35	0.7
KL4	Mean	23.8	24.1	24.7	24.2	30.0	65.0	72.5	0.24	0.44	1.1
(n=80)	S.D.	2.2	2.1	2.2	2.1	2.4	6.8	11.6	0.12	0.15	0.2
	Max.	28.0	28.0	28.9	28.1	34.3	78.6	100.0	0.73	0.98	1.7
	Min.	18.9	19.7	18.8	19.7	23.2	51.3	45.8	0.05	0.19	1.0

Note; T_a: Indoor air temperature (°C), T_g: Globe temperature (°C), T_{mrt}: Mean radiant temperature (°C), T_{op}: Operative temperature (°C), T_o: Outdoor temperature (°C), RH: Relative Humidity (%), RH_o: Outdoor relative humidity, V_a: Indoor air velocity (m/s), I_{cl}: Clothing insulation, M: Metabolic rate, n: Number of samples, S.D.: Standard deviation, Max.: Maximum, Min.: Minimum

Table 5
Correlation of $\boldsymbol{T_a}$ and $\boldsymbol{T_s}$

	KL1 (n=40)	KL2 (n=32)	KL3 (n=48)	KL4 (n=80)
Equation	$T_a = 0.55T_s + 11.11$	$T_a = 0.53T_s + 11.32$	$T_a = 0.57T_s + 10.24$	$T_a = 0.83T_s + 3.29$
r	0.904	0.928	0.945	0.932

Note; $\boldsymbol{T_a}$: Indoor air temperature (°C), $\boldsymbol{T_s}$: Setting temperature (°C), n: Number of samples, r: Correlation coefficient. Note; all correlation coefficients are significant (p<0.001).

Table 6
Correlation of $\boldsymbol{T_a}$ with $\boldsymbol{T_g}$, $\boldsymbol{T_{op}}$ and $\boldsymbol{T_{mrt}}$

Items	$T_g: T_a$	$T_{op}: T_a$	Items	$T_g: T_a$
Equation	$T_g = 2.74 + 0.90T_a$	$T_{op} = 2.77 + 0.90T_a$	Equation	$T_g = 2.74 + 0.90T_a$
r (*N*=200)	0.969	0.972	r (*N*=200)	0.969

Note; $\boldsymbol{T_a}$: Indoor air temperature (°C), $\boldsymbol{T_g}$: Globe temperature (°C), $\boldsymbol{T_{op}}$: Operative temperature (°C), $\boldsymbol{T_{mrt}}$: Mean radiant temperature (°C), r: Correlation coefficient, *N*: Number of samples. Note; all correlation coefficients are significant (p<0.001).

3.2 Distribution of Subjective Votes

Based on the mean values of *mTSV* in all study locations (Table 7), occupants were generally in the comfort range ($-1 \leq mTSV \leq 1$) when exposed to different air temperatures. Approximately 76% of responses were within the comfort range, as displayed in Figure 6. Moreover, the thermal sensation votes were leaning towards cooler sensation with 17% responses voted (-2) and (-3) compared to only 7% voted (+2) and no votes for (+3). All locations recorded cooler thermal sensation however KL2 has a preference for slightly warmer conditions despite having 'cooler' thermal sensation votes in average. More than half of the responses (55%) has 'neutral' sensations towards humidity (Figure 7). This may be due to the small effect of humidity has on comfort temperature [22] in addition to residing in a hot and humid country thus the occupants could have been adapted to the humid surroundings.

Table 7
Mean values of subjective votes

Office	Item	*mTSV*	*TP*	*HS*	*HP*
KL1	Mean	-0.6	0.4	-0.4	0.3
(n=40)	S.D.	0.7	0.7	0.7	0.6
KL2	Mean	-0.3	-0.2	0.0	0.5
(n=32)	S.D.	1.0	0.8	0.8	0.5
KL3	Mean	-0.6	0.2	0.4	-0.2
(n=48)	S.D.	1.4	1.2	1.1	0.6
KL4	Mean	-0.3	0.0	0.0	0.2
(n=80)	S.D.	1.2	1.1	1.0	0.8

Note; m*TSV*: Modified Thermal Sensation Vote, *TP*: Thermal Preference, *HS*: Humidity Sensation, *HP*: Humidity Preference, *OC*: Overall Comfort, *n*: Number of samples

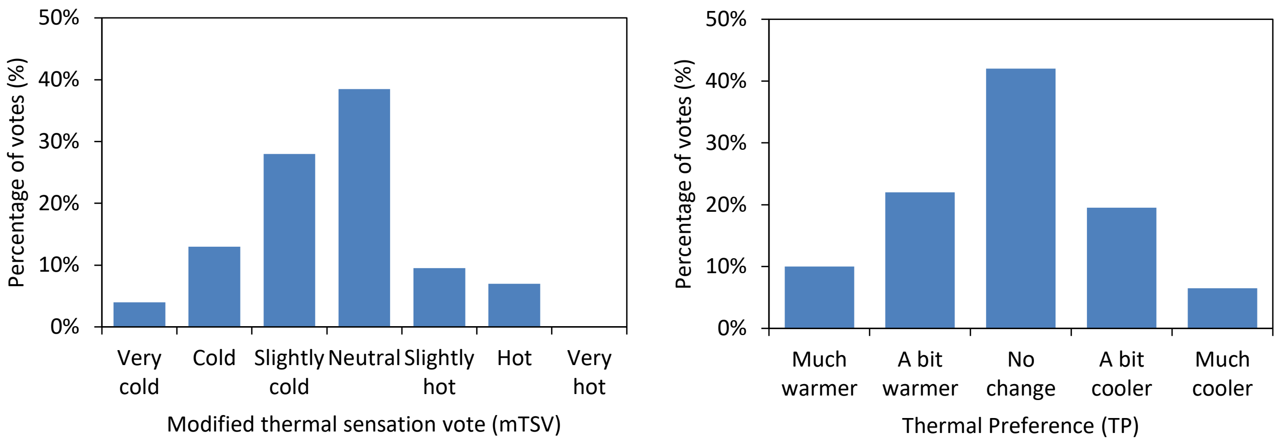


Fig. 6. Percentage votes of modified thermal sensation vote and thermal preference

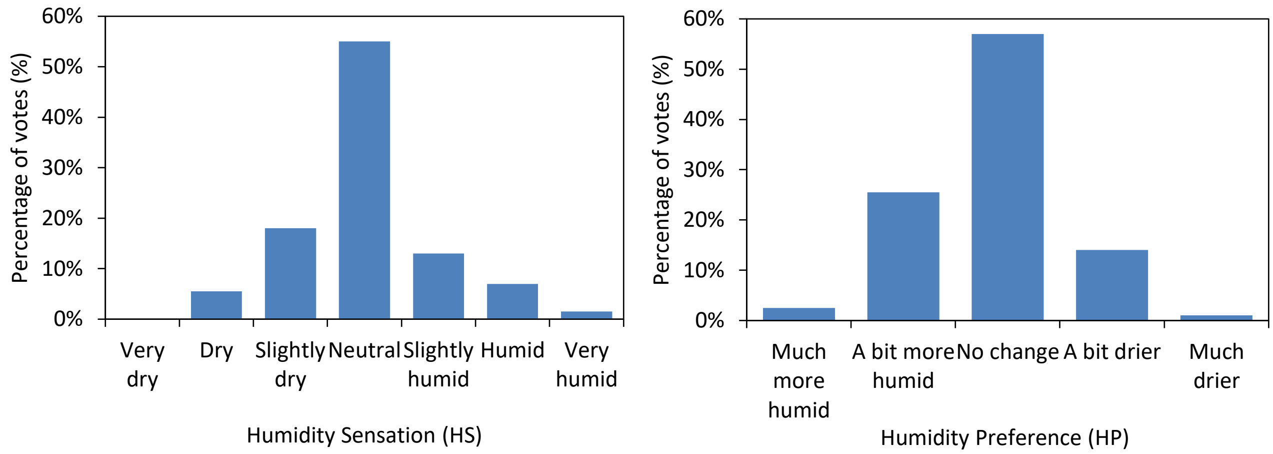


Fig. 7. Percentage votes of humidity sensation and humidity preference

3.3 Comfort Temperature
3.3.1 Regression method

Determining comfort temperature, T_c via regression involves finding the neutral temperature by examining the relationship between $mTSV$ and T_{op} as shown in Figure 8 and can be represented as below

$$mTSV = 0.34T_{op} - 8.71 \; (N = 200, R^2 = 0.414, S.E. = 0.029, p < 0.001) \tag{1}$$

where R^2 is the coefficient of determination, *N* is the number of samples, *S.E.* is the standard error of regression coefficient, and *p* is the significance level of regression coefficient. Referring to Eq. (1), comfort temperature when *mTSV=0* or 'neutral' is 25.6°C. Moreover, 2.9°C is contributed for every +1 scale of unit change in *mTSV* based on the slope of regression lines (0.34units/°C). Due to the 2.9°C scale-based change, regression method is unreliable and in line with previous studies [15,25]. Hence, Griffiths method is adopted to find comfort temperature

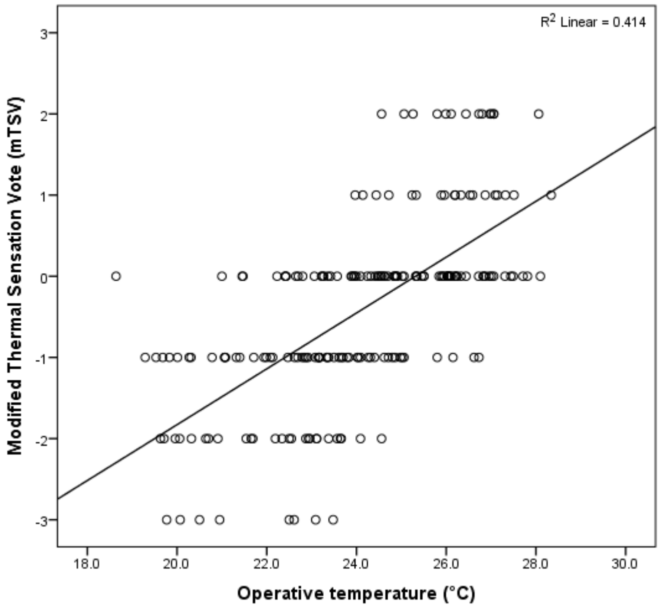


Fig. 8. Relation of modified thermal sensation vote and operative temperature

3.3.2 Griffiths method

On account of low and unreliable slope of regression line, comfort temperature was estimated using Griffiths method by calculating T_c from each response using the following equation

$$T_c = T + \frac{(0+mTSV)}{\alpha} \quad (2)$$

where T_c is comfort temperature, T is any of the thermal index ($T_a, T_g, T_{mrt}, T_{op}$), $mTSV$ is the modified thermal sensation vote and α is the Griffiths constant. In this study, $\alpha = 0.50$ is used as previously practised by Damiati *et al.,* [13], Mustapa *et al.,* [25] and Khalid *et al.,* [15] for comfort temperature in hot and humid countries. Comfort temperature found in this study is 24.9°C as shown in Table 8 and 9.

Table 8
Comfort temperature using Griffiths method

Item	T_{ca}(°C)	T_{cg}(°C)	T_{cmrt}(°C)	T_{cop}(°C)
Mean	24.6	24.9	25.4	24.9
S.D.	2.0	2.0	2.1	1.9

Note; T_{ca}: Comfort air temperature (°C),T_{cg}: Comfort globe temperature (°C), T_{cmrt}: Comfort mean radiant temperature (°C), T_{cop}: Comfort operative temperature (°C)

Table 9
Comfort temperature comparison with mean operative temperature

	T_{cop}(°C)	T_{mop}(°C)	
Item	Griffiths'	mTSV = 0	OC = 5 or 6
Mean	24.9	24.8	24.2
S.D.	1.9	1.9	2.1

Note; T_{cop}: Comfort operative temperature (°C), T_{mop}: mean operative temperature (°C), *mTSV*: Modified thermal sensation vote, *OC*: Overall comfort

We also compared our results with previous study that adopted Griffiths method to estimate comfort temperature in cooling mode ventilation. The T_c in this study is much lower than previous studies as depicted in Table 10. In comparison to previous studies, occupants in this study experienced varying thermal conditions and felt comfortable at lower temperature.

Table 10
Comparison of comfort temperature from previous studies adopting Griffiths method

Reference	Location	N	T_c(°C)	
			Mean	S.D.
This study	Kuala Lumpur, Malaysia	200	24.9	1.9
Mustapa *et al.,* [25]	Fukuoka, Japan (Summer)	222	26.6	1.6
Damiati *et al.,* [13]	Kuala Lumpur and Shah Alam, Malaysia	1114	25.6	2.2
	Bandung, Indonesia	91	26.3	2.3
	Singapore	14	26.4	2.1
	Japan (Summer)	418	25.8	1.4

Note; T_{cop}: Comfort temperature (°C), N: Number of samples, S.D.: Standard deviation

4. Conclusions

This study presented the thermal sensation of occupants in postgraduate office space with cooling mode (CL) in Kuala Lumpur, Malaysia at different set-point air temperature ranging from 18.0°C o 28.6°C. During field measurement, thermal environments and personal parameters were recorded objectively while thermal sensations were subjectively taken via questionnaire yielding 200 responses. Occupants mainly feels comfortable with 76% of the votes falls within the comfort range with average thermal sensation vote (TSV) of -0.4.

Adaptation of occupants in humid country could be the contributing factor to the major portion of responses (55%) voted ‘neutral’ humidity sensation and prefers no change. Comfort temperature estimated by regression analysis was found to be 25.6°C while Griffiths method approximated 24.9°C, close to mean values of operative temperature. The comfort temperature found in this study shows that the current minimum recommendation set by the Malaysian government in non-residential buildings to conserve energy does not sacrifice comfort of occupants.

Acknowledgement
This research was funded by a grant from Johnson Controls-Hitachi Air Conditioning vot 4B395.

References
[1] Pérez-Lombard, Luis, José Ortiz, and Christine Pout. "A review on buildings energy consumption information." *Energy and buildings* 40, no. 3 (2008): 394-398.
[2] Huang, Shaopeng, Makoto Taniguchi, Makoto Yamano, and Chung-ho Wang. "Detecting urbanization effects on surface and subsurface thermal environment—A case study of Osaka." *Science of the total environment* 407, no. 9 (2009): 3142-3152.
[3] Ichimura, Masakazu. "Urbanization, urban environment and land use: challenges and opportunities." In *Asia-Pacific Forum for Environment and Development, Expert Meeting*, vol. 23. 2003.
[4] Li, Xiaoma, Yuyu Zhou, Sha Yu, Gensuo Jia, Huidong Li, and Wenliang Li. "Urban heat island impacts on building energy consumption: A review of approaches and findings." *Energy* 174 (2019): 407-419. https://doi.org/10.1016/j.energy.2019.02.183
[5] Feriadi, H., N. H. Wong, S. Chandra, K. W. Cheong, and K. W. Tham. "Redefining appropriate thermal comfort standard for naturally ventilated buildings in tropics (Singapore and Indonesia perspective)." *Indoor Air* (2002): 110-115.
[6] Feriadi, Henry, and Nyuk Hien Wong. "Thermal comfort for naturally ventilated houses in Indonesia." *Energy and buildings* 36, no. 7 (2004): 614-626.

https://doi.org/10.1016/j.enbuild.2004.01.011

[7] Toe, Doris Hooi Chyee, and Tetsu Kubota. "Development of an adaptive thermal comfort equation for naturally ventilated buildings in hot–humid climates using ASHRAE RP-884 database." *Frontiers of Architectural Research* 2, no. 3 (2013): 278-291. https://doi.org/10.1016/j.foar.2013.06.003

[8] Frontczak, Monika, and Pawel Wargocki. "Literature survey on how different factors influence human comfort in indoor environments." *Building and environment* 46, no. 4 (2011): 922-937. https://doi.org/10.1016/j.buildenv.2010.10.021

[9] Standard, A. S. H. R. A. E. "Standard 55–2017 thermal environmental conditions for human occupancy." *Ashrae: Atlanta, GA, USA* (2017).

[10] CEN, EN15251. "15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics." *European Committee for Standardization, Brussels, Belgium* (2007).

[11] ISO, ISO. "Standard 7730." *Ergonomics of the Thermal Environment–Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria, ISO, Geneva* (2005).

[12] Edelman, Alexandra, Andrea Gelding, Elena Konovalov, Rodney McComiskie, Anne Penny, Nicholas Roberts, Shelley Templeman et al. "State of the Tropics 2014 report." (2014).

[13] Damiati, Siti Aisyah, Sheikh Ahmad Zaki, Hom Bahadur Rijal, and Surjamanto Wonorahardjo. "Field study on adaptive thermal comfort in office buildings in Malaysia, Indonesia, Singapore, and Japan during hot and humid season." *Building and Environment* 109 (2016): 208-223.

[14] Sekhar, S. C. "Thermal comfort in air-conditioned buildings in hot and humid climates–why are we not getting it right?." *Indoor air* 26, no. 1 (2016): 138-152. https://doi.org/10.1111/ina.12184

[15] Khalid, Waqas, Sheikh Ahmad Zaki, Hom Bahadur Rijal, and Fitri Yakub. "Investigation of comfort temperature and thermal adaptation for patients and visitors in Malaysian hospitals." *Energy and Buildings* 183 (2019): 484-499.

[16] Rodriguez, Carolina M., and Marta D'Alessandro. "Indoor thermal comfort review: The tropics as the next frontier." *Urban Climate* 29 (2019): 100488. https://doi.org/10.1016/j.uclim.2019.100488

[17] Malaysian Standard, M. S. "1525: 2014." *Energy Efficiency and Use of Renewable Energy for Non-residential Buildings–Code of Practice.(Second Revision)[Google Scholar]* (2014).

[18] Singapore Spring. "Singapore standard ss 554: 2009: Code of practice for indoor air quality for air-conditioned buildings." *Building and Construction Standards Committe* (2009).

[19] Nasional, Badan Standardisasi. "Standar Nasional Indonesia (Indonesian National Standardization)-SNI 6390: 2011 Konservasi Energi Sistem Tata Udara Bangunan Gedung." *BSN: Jakarta, Indonesia* (2011).

[20] Han, Jie, Guoqiang Zhang, Quan Zhang, Jinwen Zhang, Jianlong Liu, Liwei Tian, Cong Zheng et al. "Field study on occupants' thermal comfort and residential thermal environment in a hot-humid climate of China." *Building and Environment* 42, no. 12 (2007): 4043-4050. https://doi.org/10.1016/j.buildenv.2006.06.028

[21] Wu, Zhibin, Nianping Li, Pawel Wargocki, Jingqing Peng, Jingming Li, and Haijiao Cui. "Field study on thermal comfort and energy saving potential in 11 split air-conditioned office buildings in Changsha, China." *Energy* 182 (2019): 471-482. https://doi.org/10.1016/j.energy.2019.05.204

[22] Amai, Hideyuki, Shin-ichi Tanabe, Takashi Akimoto, and Takeshi Genma. "Thermal sensation and comfort with different task conditioning systems." *Building and Environment* 42, no. 12 (2007): 3955-3964. https://doi.org/10.1016/j.buildenv.2006.07.043

[23] Ajaji, Youness, and Philippe André. "Thermal comfort and visual comfort in an office building equipped with smart electrochromic glazing: An experimental study." *Energy Procedia* 78 (2015): 2464-2469.

[24] Wu, Zhibin, Nianping Li, Pawel Wargocki, Jingqing Peng, Jingming Li, and Haijiao Cui. "Field study on thermal comfort and energy saving potential in 11 split air-conditioned office buildings in Changsha, China." *Energy* 182 (2019): 471-482. https://doi.org/10.1016/j.energy.2019.05.204

[25] Wu, Zhibin, Nianping Li, Pawel Wargocki, Jingqing Peng, Jingming Li, and Haijiao Cui. "Field study on thermal comfort and energy saving potential in 11 split air-conditioned office buildings in Changsha, China." *Energy* 182 (2019): 471-482. https://doi.org/10.1016/j.energy.2019.05.204