Investigation of Thermal Comfort at Different Temperature Settings for Cooling in University Building

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ABSTRACT

This paper presented the results of a study conducted on thermal comfort in a postgraduate office of the Malaysia Japan International Institute of Technology (MJIIT, UTM, Kuala Lumpur). The aim of the study was to verify the thermal comfort associated with different air conditioning (AC) thermostat set point temperatures in the cooling (CL) mode. The relevant temperature set points were 20 °C, 24 °C, and 28 °C, as well as the Japanese so-called 'cool biz mode' set point of 28 °C. The thermal sensation vote (TSV) in relation to these CL modes were –0.4, 0.0, 0.8, and –0.1, respectively. These results indicated that at the CL mode of 28 °C, the occupants felt slightly warmer compared to the CL modes of 20 °C, 24 °C, and the cool biz mode. The results of the linear regression analysis indicated the thermal comfort range as 25.3 °C to 26.2 °C, which was close to the range of 25.6 °C to 26.1 °C indicated by employing Griffiths' method.

Keywords: *Thermal Comfort, TSV, Thermostat Set Points, Cool Biz*

Introduction

Kuala Lumpur is situated at latitude 3°7' above the equator and longitude 101°33', in which according to the Köppen-Geiger climate classification, it indicates that the city has a tropical rainforest (Af) climate. The daytime temperatures range between 29 °C and 34 °C, and the relative humidity is 70–90% throughout the year [1]. In such a hot and humid climate,

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air-conditioning (AC) is essential to provide thermal comfort, especially in commercial buildings. However, the AC systems are responsible for almost 57% of the energy consumption of office buildings [2]. Consequently, it is important to control or limit the use of AC systems to conserve energy, provided that indoor thermal comfort is not compromised. Kwong et al. (2014) estimated that an AC set point of 2 °C warmer could bring about a reduction of 2150 GWh in the annual energy demand in Malaysia. In addition, the emission of greenhouse gases could be reduced by 1.36×10^9 kg [3]. Daghigh (2015) indicated that the temperature for commercial buildings should be between 23 °C and 26 °C to promote energy saving [1]. A study conducted by Sekhar (1995) in Singapore indicated that changing the thermostat set point from 23 °C to 26 °C could reduce the energy utilised for cooling by 13% [4]. Karyono (2005) conducted a research on the central AC system of a building in Jakarta and found it was relevant to raise the temperature of the chilled water from 5.5 °C to 6.5 °C instead of changing the individual thermostat settings [5]. In Singapore, Indonesia, and Thailand, the recommended temperature settings are 25–27 °C, 24–27 °C, and 24–26 °C, respectively [6]–[8]. In Japan, the government has proposed a temperature setting of 28 °C (the so-called 'cool biz' mode) for office buildings. However, in Malaysia, the proposed thermostat set point of 24 °C was not implemented effectively in office buildings. This is ascribed to the occupants of office buildings in tropical regions who prefer the indoor temperature to be lower than 20 °C because of the high daytime outdoor temperature which is approximately 32 °C [1]. Various types of AC systems are used in office buildings such as multi-split units and central AC systems. The advantage of multi-split units is that the temperature can be regulated individually by the occupants. In contrast, central AC systems cannot accommodate individual preferences, as the temperature of the entire building is controlled from a centralised AC unit.

The main objective of this study was to determine the thermal comfort of occupants at set point temperatures in the cooling mode (CL) of 20 °C, 24 °C, and 28 °C. In addition, we compared the Japanese thermal comfort cool biz mode of 28 °C [9]. Three different AC thermostat set-point temperatures were selected, although the occupants in Malaysia usually prefer an office temperature of 20 °C or lower. However, such a low temperature could over cool the interior and could cause cold discomfort. In comparison, the indoor temperature in Malaysia as recommended by the main energy provider, Tenaga Nasional Berhad (TNB), and the Energy Commission (Suruhanjaya Tenaga [ST]) is that AC units be set at 24 °C [10] to reduce the energy consumption of these cooling systems and this setting is quite lower compared to 28 °C Japanese ‘cool biz’.

Research Methodology

Building and occupant information

The study was conducted in a postgraduate office, located in the building of the Malaysia Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia (UTM), Kuala Lumpur. The measurements were conducted on certain daytime of office hour during the period of August 2015, December 2015 and January 2016. Figure 1 shows the floor plan of the site measurement. The office has five areas; namely, the simulation room, pantry, partition 1, partition 2, and the leisure room. The data collection was done in partition 1 and partition 2, as these are the most occupied areas, as shown in Figure 2. A blind covers the large window in partition 1, whereas partition 2 has no window. The general information about the office and the occupants is summarised in Table 1.

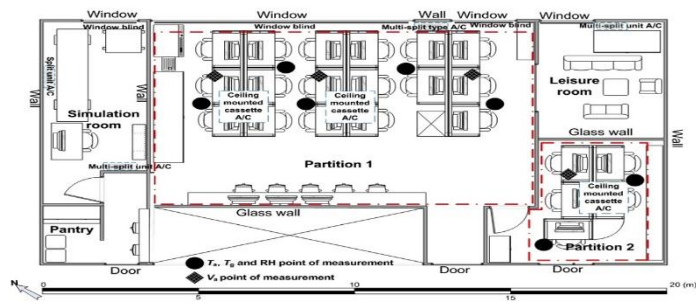


Figure 1: Layout of postgraduate office at Level 10 MJIIT, UTM, Kuala Lumpur. [Black circles indicate the locations of sensor T_a, T_g, and RH; Black diamonds indicate the locations of sensor V_a.]

(a) (b)

Figure 2: Photograph showing (a) partition 1 and (b) partition 2

Table 1: Summary of the postgraduate office conditions

Building	Floor	Spaces in office	No. of tables	Type of AC system	Window blind	Window to floor ratio
MJIIT	10	Partition 1	17	ceiling cassette and multi-split unit	Closed	0.4
		Partition 2	5	ceiling cassette	-	0.0

AC: air conditioning system

The occupants in this office controlled the CL mode of the three ceiling-mounted cassette-type AC units and one multi-split type AC unit. The occupants have been exposed to this cooling condition for more than six months.

Comfort survey responses

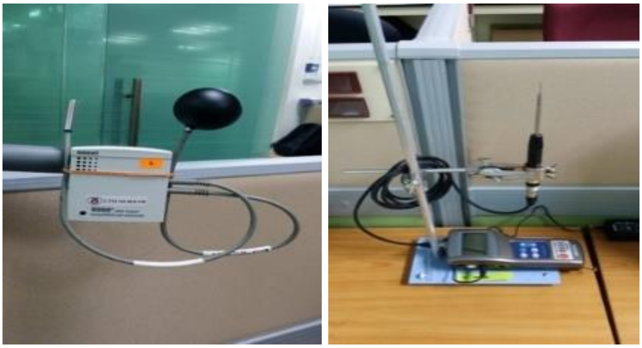
At the beginning of the field measurement campaign, we received relatively few responses; therefore, we repeated the measurements relevant to the different thermostat set-point temperatures. The measurements were conducted over several extended survey periods to increase the number of the responses. This means that the respondents answered multiple questionnaires over the measurement period. We obtained 123, 135, and 108 responses from 28 individuals for the CL mode temperatures of 20 °C, 24 °C, and 28 °C, respectively, as shown in Table 2. The occupants comprised 10 males (35.7%) and 18 females (64.3%). The average age of the males in the office was 26 years (standard deviation, S.D. = 3 years) and that of the females was 24 years (S.D. = 3 years).

Table 2: Number of responses over the measurement period

Thermostat set-point temperature	Measurement period	Number of responses
20 °C	9 days	123
24 °C	13 days	135
28 °C	9 days	108

Indoor measurements

Field measurements were conducted every weekday when a maximum number of occupants were present in the office room. During the comfort survey conducted at each table, the sensors which were placed close to the occupants collected the data on the hot spot of the space. Four indoor environmental parameters were measured; namely, the air temperature (T_a), relative humidity (RH), globe temperature (T_g), and the air speed (V_a). All the instruments were fixed in place, with the sensors placed at a height of 1.1 m above the floor. The ONSET HOBO Temperature/Relative Humidity (U12-013) thermo recorder (refer to Figure 3a) was used to measure the T_a, RH, and T_g at seven different locations, and the Kanomax Climomaster of hot-wire anemometer (needle probe omni-directional 6542-2G) was used to measure V_a (refer to Figure 3b) at four different locations in the office.



(a) (b)

Figure 3: The instruments used for physical measurement (a) ONSET HOBO Temperature/Relative Humidity thermo recorder and (b) Kanomax Climomaster hot-wire anemometer.

Comfort survey

On the field survey days, the thermal-comfort survey forms were distributed to the occupants, with the request that the forms be completed immediately. We recorded the 'right-here-right-now' responses of the occupants relevant to their perceptions of the indoor environment. The questionnaire included both demographic information (e.g. gender, age, and current health conditions) and thermal comfort questions (e.g. thermal sensation and preferences scale as shown in Table 3 below). A metabolic rate value of 1.2 Met was assumed for the sedentary office workers.

Table 3: Scale options of the thermal comfort survey.

Scale	Thermal sensation	Thermal preference
+3	Hot	
+2	Warm	Much cooler
+1	Slightly warm	Slightly cooler
0	Neutral	No change
–1	Slightly cool	Slightly warmer
–2	Cool	Much warmer
–3	Cold	

Results and Discussions

Indoor environment

The environmental measurements at the individual places in the room were captured as described previously. The average data were compared with our previous field measurements for the cool biz mode of 28 °C in Fukuoka during the summer season (August 2014) [9]. The temperature was considerably high, with a daily mean outdoor temperature of 26.2 °C (S.D. = 1.0 °C) and daily maximum outdoor temperature of 34.3 °C. A summary of the environmental variables measured during the survey is shown in Table 4.

Table 4: Distribution of environmental variables in each CL mode

	Kuala Lumpur									Fukuoka [9]		
Mode	CL 20 °C			CL 24 °C			CL 28 °C			cool biz 28 °C		
Variables	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D	N	Mean	S.D
T_a (°C)		24.6	1.7		25.6	1.8		27.5	1.3		26.3	0.6
T_g (°C)		24.9	1.7		25.6	1.5		27.8	1.3		26.4	0.6
T_o (°C)	123	28.5	1.3	135	28.5	0.8	108	29.6	0.8	222	26.2	1.0
RH (%)		51.5	5.4		53.8	4.4		49.0	5.1		63.3	5.9
V_a (m s^{-1})		0.26	0.16		0.24	0.12		0.25	0.18	188	0.19	0.08

T_a: indoor air temperature; T_g: indoor globe temperature; T_o: outdoor temperature; V_a: indoor air velocity; *RH*: indoor relative humidity; N: number of samples; S.D.: standard deviation.

In this case study, the mean T_a and T_g in the CL mode temperature of 20 °C (AC thermostat set-point temperature) was 4.6 °C higher than the thermostat setting temperature. Relevant to the CL mode temperature of 24 °C, the mean was slightly higher (1.6 °C) and relevant to the CL mode thermostat setting of 28 °C, and the mean was slightly lower (0.5 °C) than the regulated temperature. With regard to the cool biz mode of 28 °C in Fukuoka, Japan, the mean values of T_a and T_g were slightly lower than those in the CL mode of 28 °C in Kuala Lumpur, Malaysia. This difference could be ascribed to the difference in outdoor temperature between Kuala Lumpur and Fukuoka.

A moderate RH of 49–64% was found for each CL mode in Kuala Lumpur and Fukuoka, which could be ascribed to the AC controlling the humidity level of the indoor space. All the RH percentages were within the acceptable range of 40–70%.

Furthermore, relatively little change was observed in the mean V_a for each CL mode in the Kuala Lumpur case study. However, the V_a value (0.25 m s^{-1}) was high compared to the cool biz mode in Fukuoka (0.19 m s^{-1}). The constant high mean values of V_a could be ascribed to only indoor air being circulated by the AC and the electric pedestal fan. In addition, as the windows and doors remained closed at all times, no wind flow from the outside could enter the office room.

Thermal sensation and preference vote

This section presents an analysis of the individual thermal sensation vote (TSV) and the thermal preference (TP). Table 5 shows the percentage of each TSV vote category. A summary of the descriptive statistics of the votes relevant to each CL mode in Kuala Lumpur and Fukuoka is presented in Table 6.

Table 5: Distribution of the thermal sensation vote

Thermal sensation vote	Percentage of each thermal sensation vote (%)			
	Kuala Lumpur			Fukuoka
	CL 20 °C	CL 24 °C	CL 28 °C	Cool biz 28 °C
Hot	0.8	0.7	6.5	–
Warm	12.2	8.9	22.2	–
Slightly warm	13.8	23.0	30.6	19.8
Neutral	22.8	31.1	28.7	55.9
Slightly cool	30.9	29.6	12.0	21.6
Cool	15.4	6.7	–	2.7
Cold	4.1	–	–	–

Table 6: Descriptive statistics of thermal sensation and preference votes

	Kuala Lumpur									Fukuoka [9]		
Mode	CL 20 °C			CL 24 °C			CL 28 °C			Cool biz 28 °C		
Variable	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
TSV	123	–0.4	1.4	135	0.0	1.1	108	0.8	1.1	222	–0.1	0.7
TP		0.1	0.8		0.3	0.7		0.7	0.6		0.2	0.5

TSV: thermal sensation vote; TP: thermal preference; N: number of samples; S.D.: standard deviation.

Approximately 67% of the TSV for the CL mode temperature of 20 °C was in the central three categories (–1, 0, and +1). The TSV mean value was -0.4, between the ‘neutral’ and ‘slightly cool’ vote categories, and the occupants preferred ‘no change’ to their current thermal condition. Approximately 83% of the TSV for the CL mode temperature of 24 °C was in the same categories as those of the 20 °C mode, and the mean value of TSV was zero ('neutral'). The highest percentage, indicating that the occupants felt mostly neutral, was in this CL mode temperature. Approximately 71% of the TSV for the CL mode temperature of 28 °C was in similar categories as those of the other temperatures, and the mean value of TSV was 0.80, between the ‘neutral’ and ‘slightly warm’ vote categories. The occupants indicated that they preferred a cooler temperature. In addition, more than 97% of the TSV relevant to the cool biz mode in Fukuoka was in the same categories as those of the other temperatures. In this instance, the mean value of TSV was close to zero ('neutral') and the occupants preferred ‘no change’. This result indicates that more than 80% of the occupants were comfortable at the CL mode of 24 °C and the cool biz mode of 28 °C.

Comfort temperature by regression analysis

The TSV for individuals varies because of the variation in the operative temperature (T_{op}) in the room, as well as the position of each individual inside the room. The T_{op} is calculated using the Equation (1) [11]:

$$T_{op} = \frac{\left(T_a \sqrt{10V_a}\right) + T_{mrt}}{\left(1 + \sqrt{10V_a}\right)} \quad (1)$$

where T_a is the indoor air temperature (°C), V_a is air speed (m s^{-1}) *and* T_{mrt} is the mean radiant temperature (°C).

Using regression analysis, the comfort temperature can be estimated when the TSV vote of the occupants in the neutral category intercepts the linear regression lines, as shown in Figure 4. This figure shows a plot of the individual TSV values versus T_{op} for each set point temperature in the CL mode. The results of the linear regression analysis for the Japanese cool biz mode was found not statistically significant [9].

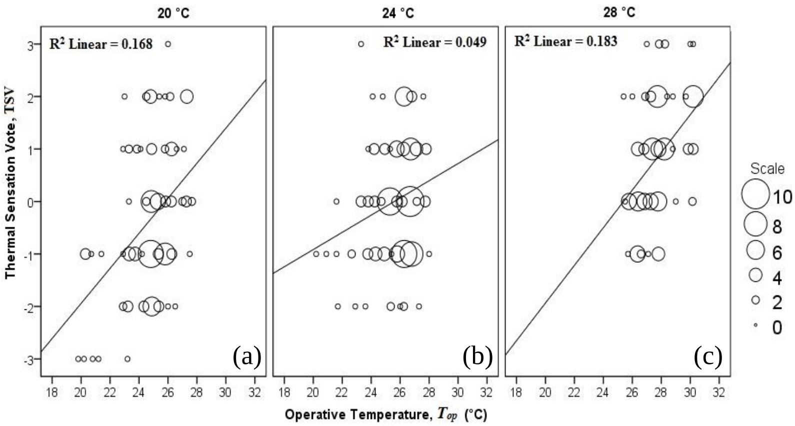


Figure 4: Regression analysis of thermal sensation votes in relation to operative temperature for thermostat set point (a) 20°C (b) 24°C and (c) 28°C

The regression analysis equations for the CL mode temperatures are as follows:

CL mode temperature of 20 °C in Equation (2):

$$TSV = 0.33T_{op} - 8.62 \quad (R^2 = 0.168, n = 123, S.E = 0.068, p < 0.01) \tag{2}$$

CL mode temperature of 24 °C in Equation (3):

$$TSV = 0.16T_{op} - 4.19 \quad (R^2 = 0.049, n = 135, S.E = 0.062, p < 0.05) \tag{3}$$

CL mode temperature of 28 °C in Equation (4):

$$TSV = 0.36T_{op} - 9.11 \quad (R^2 = 0.183, n = 108, S.E. = 0.074, p < 0.01) \tag{4}$$

CL mode for all data in Equation (5):

$$TSV = 0.33T_{op} - 8.40 \quad (R^2 = 0.237, n = 366, S.E. = 0.031, p < 0.01) \tag{5}$$

where R^2 is coefficient of determination; n indicates number of sample; S.E. is standard error of the regression coefficient; p indicates significance level of regression coefficient.

The slopes in Equation (2) to Equation (4) represent the extent of the thermal sensation change according to the variation of T_{op} in each CL modes. The slopes of TSV in the CL mode temperatures of 20 °C, 24 °C, and 28 °C were 0.34 units/°C, 0.16 units/°C and 0.36 units/°C, respectively. The slope of linear regression in the CL mode temperature of 24 °C is lower than CL mode temperature of 20 °C and 28 °C. This indicates that thermal response of the occupant is less sensitive [12]. This result implies that the respondents exposed to the CL mode temperature of 24 °C could tolerate a broader variation in the T_{op} compared to the CL mode temperatures of 20 °C and 28 °C. For the overall data of CL mode, the thermal response is 0.33 units/°C (refer Equation 5) which indicates the temperature value per sensation scale of the TSV is 3.0 °C/unit. This result implies that the comfort temperatures (T_c) relevant to the temperatures 20 °C, 24 °C, and 28°C were 25.7 °C, 26.2 °C, and 25.3 °C, respectively, indicating higher T_c was found for the CL mode temperature of 24 °C.

Comfort temperature according to Griffiths' method

As using regression analysis for the cool biz mode did not return statistically significant results, the Griffiths' method was employed to determine T_c [9]. The Griffiths method was used to calculate the T_c for each individual from the respondents TSV votes and the mean temperature by applying Equation (6) [13], [14].

$$T_c = T + \frac{(0 - TSV)}{\alpha} \tag{6}$$

where T is the indoor air temperature (°C) or globe temperature (°C) and α is the regression coefficient. Therefore, when TSV equals zero, the comfort temperature is equal to the substituted temperature.

The mean T_{cg} was calculated by using the T_g data with Griffiths' constant of 0.50, as shown in Table 7. The mean T_{cg} values for the case study in Malaysia were 25.6 °C for the CL mode temperatures of 20 °C and 24 °C, and 26.1 °C for the CL mode temperature of 28 °C. However, the Fukuoka data analysis indicated a mean T_{cg} of 26.6 °C. The mean T_{cg} was similar to the mean temperature for TSV equal to zero ('neutral'), or TP equals to zero ('no change'). In addition, the value of T_{cg} for the CL mode temperature of 28°C was slightly higher (1 °C) than that of the cool biz mode. The higher value of T_{cg} is ascribed to the significant air movement in the CL mode temperature of 28 °C. This finding is in accordance with the results reported by Indraganti et al. [15].

In addition, we compared our results with those of other studies that employed Griffiths' method to determine temperature comfort, as shown in Table 8. The mean Griffiths' comfort temperature found by the current study was similar to the results obtained for Bandung and Fukuoka. However, it was approximately 1.3 °C lower than that for Tokyo.

Table 7: Descriptive statistics for comfort temperature calculated by Griffiths' method

	Comfort temperature, T_{cg}								
	Griffiths' method			TSV = 0			TP = 0		
CL Mode	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
20 °C	123	25.6	2.5	28	25.8	1.1	47	24.9	1.5
24 °C	135	25.6	2.4	42	25.6	1.4	66	25.3	1.7
28 °C	108	26.1	2.0	31	27.1	1.2	25	27.4	1.1
Cool biz 28 °C [9]	222	26.6	1.6	124	26.4	0.7	158	26.5	0.6

N: number of samples; S.D.: standard deviation.

Table 8: Comparison of comfort temperature T_{cg} with other studies on cooling modes in offices

Reference	Area	Comfort temperature T_{cg} (°C)		
		N	Mean	SD
This study	Kuala Lumpur, Malaysia	108	26.1	2.0
Mustapa *et al.* (2016) [9]	Fukuoka, Japan	222	26.6	1.6
Indraganti *et al.* (2013) [15]	Tokyo, Japan	1979	27.4	2.2
Damiati *et al.* (2015) [16]	Bandung, Indonesia	91	26.2	2.3

T_{cg}: Comfort temperature; N: Number of samples; S.D.: Standard deviation.

Conclusion

We investigated the thermal comfort in a postgraduate office of MJIIT, UTM, Kuala Lumpur by using field measurements and a survey on the thermal comfort. We compared the results of this study with those obtained for other geographical regions. In addition, a comparison was made between the culture of AC usage in Kuala Lumpur and that in Fukuoka (Japan).

The thermal sensation vote (TSV) in the CL mode temperatures of 20 °C, 24 °C, 28 °C, and the cool biz mode were –0.4, 0.0, 0.8, and –0.1, respectively. In accordance with the increase in the thermostat set-point temperature, the TSV votes changed from slightly cool to neutral and then to slightly warm. However, the TSV vote was nearly neutral for the cool biz mode in Fukuoka, with the AC thermostat set-point temperature regulated to 28 °C. The comfort temperature indicated by linear regression analysis in the CL mode ranged between 25.3 °C to 26.2 °C. The results obtained by using Griffiths' method to calculate the T_{cg} values (25.6–26.1 °C) were close to the values obtained by using linear regression analysis.

In Malaysia, a standard AC temperature of 24 °C is recommended by the TNB for office buildings. However, an even higher set point temperature could contribute to reducing energy consumption, as shown by the cool biz mode practised in Japan. The current study has shown that a set point temperature of 24°C could be implemented to limit energy consumption without the comfort of the occupants being affected.

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