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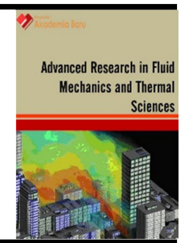

Thermal Comfort Requirements for Different Occupants in Malaysian Hospital In-patient Wards

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ABSTRACT

It is important and challenging to provide suitable thermal comfort conditions in hospital building due to widely varying conditions requirements by different types of occupants. The precise control of temperature and humidity is vital in hot-humid hospitals as these affect diseases, infections and allergies etc. indirectly. A field study comprising of thermal environment evaluation and thermal comfort survey, has been conducted in one Malaysian hospital in-patient wards with 315 respondents. Thermal comfort requirements of patients, visitors and nurses have been investigated. The patient rooms as well as nurse workstations were found bit overcooled by patients, visitors and nurses. Thermal preference of no change by patients and visitors whereas lower temperature was observed by nursing staff in wards. A bit humid air was preferred by all respondents as mean humidity sensation vote was bit drier for all of them. The air movement was acceptable for all respondents in wards as mean percentage of acceptance for every group was more than 91%. Comfort temperatures based on operative temperature for patients, visitors and nurses have been found as 25.7, 25.5 and 23.5°C which can be used as deign guides for hospital HVAC system by local building service engineers and researchers.

1. Introduction

To provide desired comfortable temperature to building users, the use of mechanical means has led to huge energy consumption in building stock which is nowadays around one third of fossil fuels consumed in buildings [1]. The demand to design and build energy efficient buildings is more serious and cost–effective solution to mitigate energy and environment issues like rising fuel prices, fossil fuel depletion, higher CO_2 concentration and global warming [2, 3]. According to Ma *et al.*, [4] the hospital's energy consumption is much higher than government office and school buildings. Hospitals are immense energy consumers due to around-the-clock operation and consume high

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energy through air-conditioning system, lighting, medical and office equipment and so on [5]. In hot-humid conditions, air-conditioning system has substantial energy share in hospitals for ensuring good indoor air quality as well as thermal comfort in hospitals. The energy consumption increases with lower temperature settings. Damiati *et al*., [6] found that 80% of occupants were thermally comfortable with the operative temperature range between 24.5-30.0°C in mechanically cooled Malaysian offices. The acceptable minimum temperature range for non-residential buildings is 23.0-27.0°C from Malaysian Standard MS1525 [7]. According to ISO/TS 14415, people with disabilities may not accept normal conditions that provide comfort to healthy occupants. The precise control of temperature and humidity is vital in hot-humid hospitals for better health and comfort of hospital occupants as these have indirect influence on diseases, infections, allergies, fungus and mold growth [8].

Preceding research studies [9-15] have been conducted in hospitals in temperate and sub-tropical climatic conditions but only few studies [16-21] have been conducted in tropics. These studies have been conducted for staff and visitors at their workplaces and facility areas respectively in hospitals but only few studies [12, 22] have been conducted for occupants of in-patients wards. Researchers [10, 12] also indicated wide variation in findings for thermal comfort of patient in temperate and sub-tropic climates. There is a need of research to determine thermal comfort requirements of different occupants of in-patient ward in all climatic regions and tropics specifically.

This research study discusses results of thermal environment evaluation as well as thermal comfort survey being conducted with patients, visitors and nurses in one private Malaysian hospital in-patient wards. The specific objectives of this study are: 1) to investigate the current indoor thermal comfort conditions in Malaysian hospital in-patient wards; 2) to investigate the comfort temperatures for patients, visitors and staff; 3) to compare comfort temperatures expressed in thermal indices: air temperature, globe temperature, mean radiant temperature and operative temperature.

2. Methodology

2.1 Location of studied building

The private hospital studied is located in heart of Kuala Lumpur, Malaysia. Kuala Lumpur is having tropical rain forest climate (Köppen climate classification) i.e. warm and sunny along with abundant rainfall during northeast monsoon season. Temperature remains constant throughout the year with maximum between 32.0-33.0°C and minimum between 23.0-25.0°C [23, 24]. During March 2014-Feburary 2015, the air temperature was low in general, which ranged between 26.0 to 30.0°C and peak at 28.0°C [25].

The field study measurements have been conducted in different hospital in-patient wards i.e. premier, medical, surgical, paediatric and maternity wards. These wards were located on 7th-11th floors in hospital building. Overall patient room types based on facilities in different wards were: single bed, double bed, four bed and executive. All the areas in wards were centrally air-conditioned (cooled) having fixed windows. Fan coil units were installed in all patient rooms whereas air handling units were installed in all nurse stations and other common areas. The patient rooms were having thermostat control for cooling except four bed rooms whereas the nurse stations and common areas were not having that controls. The physical and personal measurements have been conducted with patients and visitors in patient rooms and nurses at their workstations in different wards. Nurse stations were in common areas inside the wards.

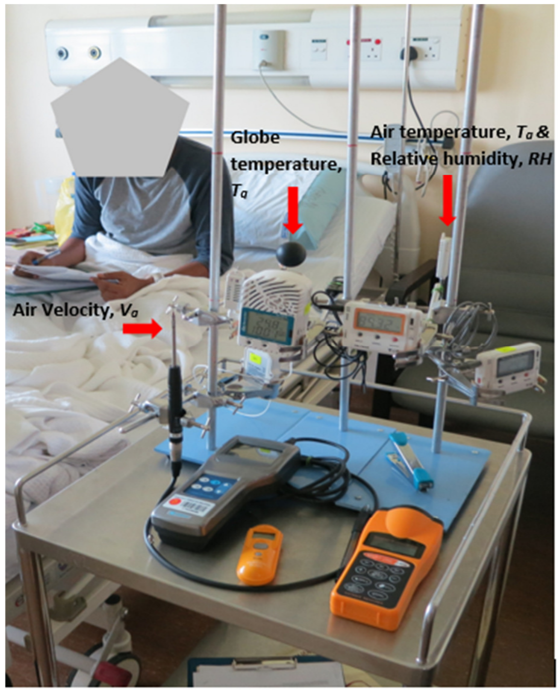

Fig. 1. Measurement equipment for T_a, T_g, V_a and *RH* setup on trolley

2.2 Thermal measurement

Thermal comfort is affected by physical and personal parameters which were measured simultaneously in hospital wards in this study. Air temperature (T_a), relative humidity (*RH*), globe temperature (T_g) and air velocity (V_a) were measured as objective physical measurements at patient bed/staff workspace height i.e. 1.1 meters within radius of 0.5 meters from respondent. All the equipment was clamped with retort stands on movable trolley as shown in Figure. 1. The trolley was moved to next respondent approximately after 10-15 minutes when comfort survey and thermal measurements were completed.

T_a and *RH* was measured through TR-77Ui and T_g was measured with TR-52i tipped with 40mm black sphere with 1 minute interval after 10 minutes. Air velocity was also measured in 10 second interval using hot wire anemometer as shown in Figure 1 and average value was recorded. The instruments specifications are mentioned in Table 1.

Table 1
Instruments Specifications

Instrument (Model No.)	Resolution	Accuracy
Thermorecorder (TR-77Ui)	0.1°C & 0.1%RH	±0.3°C(at +10°C to +40°C) ±0.5°C(at all other temperatures) ±2.5%RH(at 25°C and 20-85%RH) ±4%RH(at 25°C and 0-10%RH or 85-99%RH)
Thermorecorder (TR-52i)	0.1°C	Avg. ±0.3°C [-20 to 80°C] Avg. ±0.5°C[-40 to -20°C/80 to 110°C] Avg. ±1.0°C[-60 to -40°C/110 to 155°C]
Anemometer (Kanomax 6501-0G)	0.01m/s	±0.0125m/s[0.10-30.0m/s]

Table 2
Thermal Comfort Survey Scales

Scale	Thermal sensation vote	Thermal preference	Humidity feeling	Humidity preference	Air movement vote	Activity level
5						Walking indoor/outdoor
4					High	Seated, light work
3	Very hot		Very humid		Neither high nor low	Seated, quiet
2	Hot	Much cooler	Humid	Much more humid	Low	Reclining
1	Slightly hot	A bit cooler	Slightly humid	A bit more humid	No air movement	Sleeping
0	Neutral	No change	Neutral	No change		
-1	Slightly cold	A bit warmer	Slightly dry	A bit drier		
-2	Cold	Much warmer	Dry	Much drier		
-3	Very Cold		Very dry			

2.3 Thermal comfort survey

This is asking the users/occupants about indoor thermal environment and recording responses in questionnaire. Thermal comfort surveys were conducted with ward occupants; patients and visitors in patient rooms and nurses at their workstations simultaneously with the objective physical measurements. These surveys covered information about occupant demographics, physical strength, thermal sensation, preference and acceptability, overall comfort vote and adaptive methods. Two personal factors activity level and clothing were also recorded in questionnaire and their respective clothing insulation (clo) and metabolic rates (met) were estimated from ASHRAE standard 55-2017. The insulation from bedding accessories and chairs are not included. Thermal sensation vote was rated by modified ASHRAE 7-point scale like in [26] to avoid confusion from words “cool” and “warm” in ASHRAE 7-point scale to respondents as precaution, which is shown along with other parameters scales in Table 2.

It is very challenging and difficult to conduct field measurements in hospital wards due to management concerns about staff disturbance, patient discomfort and privacy. In this study, total 315 responses were obtained by one private hospital wards from 200 patients, 55 visitors and 60 nurses. These responses were obtained in 3 rounds in same wards with different patients and visitors but same nurses with consent of ward management. The ethical protocols and precautionary measures have been followed strictly by surveyors during assessments in hospital wards to avoid patient and staff discomfort. The field study measurements were conducted between January-March, 2016.

2.4 Mean radiant and operative temperature calculation

The two thermal indexes; mean radiant temperature (T_{mrt}) and operative temperature (T_{op}) are derived from T_a, T_g and V_a. T_{mrt} is calculated by globe thermometer by equation 1 [27]

$$T_{mrt} = [(T_g + 273)^4 + ((1.1)(10^8)(V_a^{0.6})/(\varepsilon)(D^{0.4}))\,(T_g - T_a)]^{0.25} - 273 \tag{1}$$

where "ε" refers to emissivity of the globe, taken as 0.95 for black globe and D refers to diameter of globe i.e. 0.04 meter. T_{op} is the uniform temperature of an imaginary black enclosure and the air within which an occupant would exchange same amount of heat by radiation plus convection as in the actual non uniform environment [28]. It is calculated based on T_{mrt} and average T_a by Eq. 2 [28]

$$T_{op} = AT_a + (1 - A)T_{mrt} \tag{2}$$

where A is function of relative air speed (v_r) and its value is selected as 0.5 when v_r is less than 0.2 m/s and 0.6 when v_r is within 0.2-0.6 m/s.

Table 3
Descriptive statistics for objective measurement

Respondent	Variable	T_a (°C)	T_g (°C)	T_{mrt} (°C)	T_{op} (°C)	RH (%)	AH (g/kg $_{DA}$)	V_a (m/s)
Patient	Mean	23.6	23.6	23.6	23.6	59.9	13.2	0.06
(n = 200)	S.D.	1.8	1.8	2.2	1.8	7.5	2.4	0.04
Visitor	Mean	23.0	22.9	22.8	22.9	60.1	12.8	0.07
(n = 55)	S.D.	1.3	1.3	1.6	1.3	8.4	2.5	0.04
Nurse	Mean	22.2	22.0	21.8	22.0	64.5	13.0	0.12
(n = 60)	S.D.	0.6	0.8	1.2	0.8	8.0	1.8	0.08

Note: n: Number of samples, Min: Minimum, Max: Maximum, S.D.: Standard Deviation, T_a: Air temperature, T_g: Globe temperature, T_{mrt}: Mean radiant temperature, T_{op}: Operative temperature, V_a: Air velocity, RH: Relative humidity

3. Results and discussion

3.1 Thermal environment evaluation

After compilation, the results of mean values of field measurements and survey were obtained which are presented in Table 3. The highest mean T_a measured were 23.6°C and 22.0°C in patient room and nurse station in ward.

To investigate the relation between T_a and other three thermal indices; T_{op}, T_{op} and T_{mrt}; correlation coefficients have been calculated. The values of T_{op} and T_{mrt} have been obtained from calculation whereas T_a and T_g were measured directly through instruments. Based on correlation coefficient *(r)* and regression equations as shown in Table 4, most of the correlation coefficients are nearly equal to one which show strong correlation between T_a and T_g, T_{op} and T_{mrt} as $p \leq 0.001$ i.e. all are statistically significant. The *r*-values in Table 4 show very strong positive linear relationship between T_a and T_g and T_{op} while weak positive linear relation has been found between T_a and T_{mrt} especially for nurses.

Figure 2 shows the scatterplot between T_a and T_g as representative. The linear regression lines for 3 respondents show very strong relationship between the two. The mean air velocity recorded in patient rooms and nurse stations in wards was less than 0.20m/s. The highest mean relative humidity recorded was 60% in patient rooms and 64% in nurse stations in wards. The air movement and relative humidity was within the acceptable range of 0.15-0.50 m/s and 40-70% of industry code of practice on indoor air quality by Department of safety and health (DOSH), Malaysia 2010 [29]. The mean absolute humidity found in both patient rooms and nurse stations exceeded the maximum limit of 12 g/kg$_{DA}$ of absolute humidity by ASHRAE Standard 55 [28].

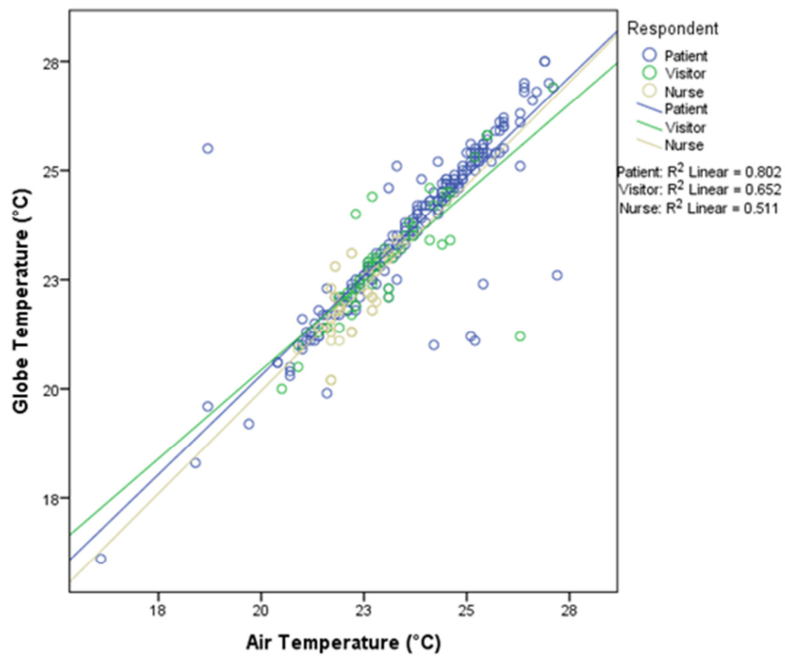

Fig. 2. Relation between globe and indoor air temperature

3.2 Thermal sensation, humidity feeling and air movement vote

The results for thermal sensation, humidity feeling and air movement vote are shown in Table 5 whereas scales used for these parameters in thermal comfort survey are presented in Table 2. Mean thermal sensation vote (*TSV*) for patient was -1.1 (slightly cold) and their mean thermal preference was 0.0 (no change) as mean metabolic rate and clothing insulation were 1.1 met and 0.44 clo as mentioned in Table 5. Similarly mean *TSV* for visitors was slightly cold and thermal preference was no change as their mean metabolic rate and clothing insulation values were 1.2 met and 0.51 clo. The malfunctioning of thermostat controllers was observed in several patient rooms which might be reason of overcooling in patient rooms as controls of these were provided to all patient rooms except four bed rooms. Mean thermal sensation vote for nurse was -0.7 (almost slightly cold) whereas thermal preference was 0.3 (towards bit cooer). It reveals that nursing staff felt slightly cold and their preference was still bit cooler as their mean metabolic rate was 1.5 met and mean clothing insulation was 0.55 clo which both were more than patients and visitors due to continuous activity and wearing of uniform. Overall, all the occupants (patients, visitors and nurses) in all wards felt slightly cold where patients and visitors preferred almost no change in temperature but nurses preferred bit cooler.

Table 4
Regression results between T_a and other thermal indexes

Respondent	Items	T_a:T_g	T_a:T_{mrt}	T_a:T_{op}
Patient	Eq.	$T_g = 0.90T_a + 2.3$	$T_{mrt} = 0.76Ta+5.6$	$T_{op} = 0.90T_a + 2.3$
(n = 200)	*r*	0.89	0.61	0.90
Visitor	*Eq.*	$T_g = 0.81T_a +4.2$	$T_{mrt} = 0.73Ta +6.0$	$T_{op} = 0.87T_a + 2.9$
(n = 55)	*r*	0.81	0.62	0.88
Nurse	*Eq.*	$T_g = 0.94T_a + 1.1$	$T_{mrt} = 0.89Ta + 2.0$	$T_{op} = 0.93T_a + 1.5$
(n = 60)	*r*	0.71	0.43	0.67

Note: n: Number of samples, *r*: correlation coefficient, Eq: equation, T_a: Air temperature (°C), T_g: Globe temperature (°C), T_{mrt}: Mean radiant temperature (°C), T_{op}: Operative temperature (°C)

Table 5
Subjective measurement results

Respondent	Item	Mean	S.D.
Patient (n = 200)	*TSV*	-1.1	1.2
	TP	0.0	0.9
	HF	-0.2	0.8
	HP	-0.3	0.7
	AV	2.5	0.7
	Clo	0.44	0.19
	Met	1.1	0.3
Visitor (n = 55)	*TSV*	-1.3	1.1
	TP	0.1	0.9
	HF	-0.3	1.0
	HP	-0.2	0.7
	AV	2.6	0.6
	Clo	0.51	0.18
	Met	1.2	0.3
Nurse (n = 60)	*TSV*	-0.7	1.3
	TP	0.3	0.9
	HF	-0.4	1.1
	HP	-0.3	0.8
	AM	2.7	0.5
	Clo	0.55	0.08
	Met	1.5	1.3

Note: n: Number of samples, S.D.: Standard Deviation, *TSV*: Thermal Sensation Vote, *TP*: Thermal Preference, *HF*: Humidity Feeling, *HP*: Humidity Preference, *AV*: Air Movement Vote, *Clo*: Clothing insulation, *Met*: Metabolic rate (Activity level)

Mean humidity feeling for patient was -0.2 (neutral) but towards slightly dry as the mean preference is -0.3 (towards slightly humid). For visitors mean humidity sensation vote was -0.3 (towards slightly dry) and their humidity preference was -0.2 (towards a bit humid). The mean humidity feeling for nurses was -0.4 (towards slightly dry) and their preference was -0.3 (towards a bit humid). Therefore overall, the occupants in all wards either in patient rooms or nurse stations felt air bit drier and preferred bit humid.

The mean air movement vote for patient was 2.5 (low) but for visitors and nurses was almost 3 (neither high nor low) as shown in Table 2. The percentage of acceptance of air movement for patients (n=200) is 91% whereas for visitors (n=55) and nurses (n=60) is almost 95% as shown in Figure 3. Therefore, overall air movement acceptance is more than 91% for all these occupants in different hospital wards.

3.2.1 Relation between thermal sensation and thermal preference

The relationship between *TSV* and thermal preference (*TP)* has been analysed separately for nurses and patients & visitors and cumulative percentages of warmer and cooler preference votes in relation to *TSV* are shown in Figure 4 and 5. It can be seen from blue and red lines that 35% of patients (n=23), 33% of visitors (n=4) and 43% of nurses (n=9) who voted for ‘neutral’ thermal sensation preferred cooler temperature whereas 12% patients, 8% visitors and 10% nurses preferred warmer temperature.

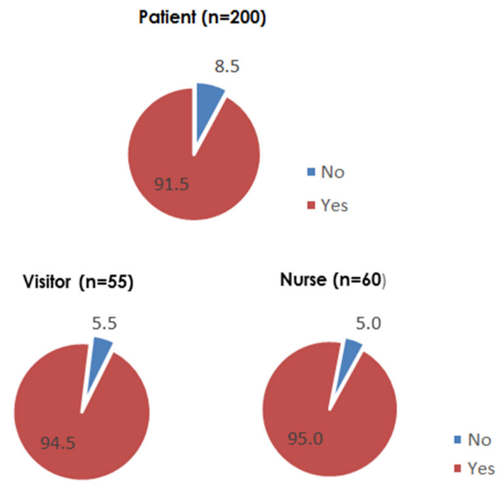

Fig. 3. Percentage of air movement acceptance

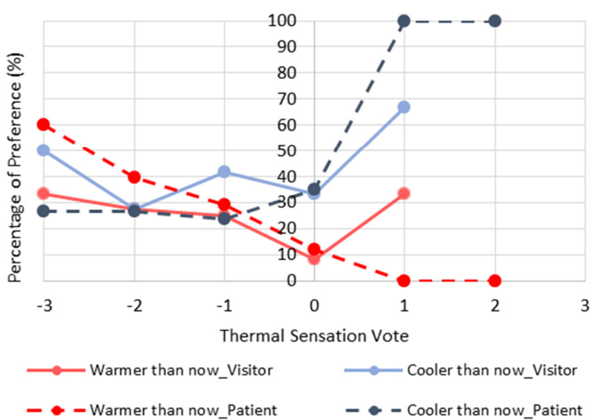

Fig. 4. Relation of *TSV* & *TP* in patient rooms

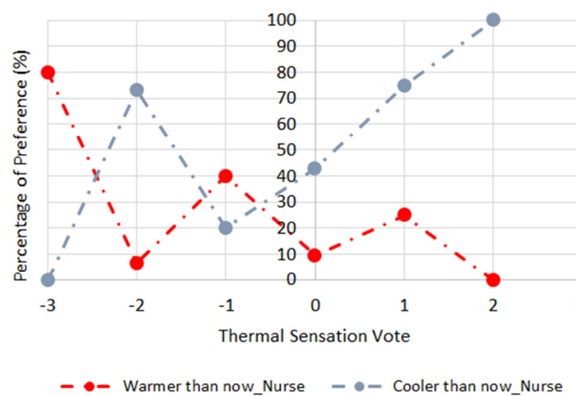

Fig. 5. Relation of *TSV* & *TP* in nurse stations

The ‘warmer than now’ vote indicates the percentage of occupants voted for -2 or -1 (much warmer or a bit warmer) on 5-point *TP* scale whereas ‘cooler than now’ vote indicates percentage of occupants voted for 2 or 1 (much cooler or a bit cooler). On left side (cooler) of thermal sensation scale, the proportion of cooler preference for patient remained almost 25%, whereas for visitors it decreased and then increased at slightly cool sensation vote and then increased again on warmer sensation on right side for both patients as well as visitors. But for nurses, the proportion of cooler preference increased from zero on cooler sensation on left side at -2 (cold) and then decreased but increased on warmer sensation on right side of scale. The proportion of warmer preference decreased on cooler sensation on left side for both patients and visitors but decreased for patients and increased for visitors on the right side of warmer sensation. This difference in preference may be due to unstable health condition of patients as compared to visitors (normal population). While for nurses it decreased on cooler sensation till -2 (cold) and then increased at -1 (slightly cold) and on warmer sensation it increased again at 1 (slightly hot) and decreased at 2 (hot). It is interesting that some patients, visitors and nurses still preferred cooler condition while voting for cool thermal sensation whereas some visitors and nurses still preferred warmer condition while voting for warmer thermal sensation. According to de Dear [30], *TP* could be a superior measure of thermal comfort of people, as the neutral *TSV* condition was not considered the preferred condition. Rijal *et al.*, [31] mentioned the reason of interesting relationship between *TSV* and *TP* in his study in Nepal that although people were satisfied with the current conditions even then most of them preferred warmer or cooler environment if possible due to their natural desire. In wards, more than 56% of thermal sensation votes of patients and nurses were within comfort range of *TSV* (-1, 0 and 1) except for visitors in patient rooms, with 40.0% votes for cold, while in contrast, 26.5% and 25.0% of votes were recorded for cold conditions for patients and nurses in their rooms and workstations as shown in Table 6.

3.3 Comfort temperature

Neutral temperature is the temperature calculated by population to be neutral on the ASHRAE scale, or comfortable, neither warm nor cool on the Bedford scale which is usually assumed to be the desired temperature [32]. Neutral temperature is also referred to comfort temperature in present study.

Table 6
Percentage of thermal sensation vote for each respondent

TSV	Patient	Visitor	Nurse
-3	15.0	10.9	8.3
-2	26.5	40.0	25.0
-1	19.0	21.8	16.7
0	33.0	21.8	35.0
1	5.0	5.5	13.3
2	1.5	-	1.7
3	-	-	-
n	200	55	60

TSV: thermal sensation vote, n: no of samples

Regression method has been used for data analysis and investigating comfort temperatures for patients, visitors and nurses in wards. Relation between *TSV* and T_{op} is shown in Figure 6. The linear regression equation obtained for patients is shown in equation 3

$$TSV = 0.14T_{op} - 4.34, (n = 200, R^2 = 0.039, p = 0.005) \quad (3)$$

The regression coefficients are not statistically significant for nurses and visitors but significant as shown in equation 3. The range of temperatures in this study as shown in Table 3 is narrow due to which regression method is unreliable for assessing comfort temperature. The comfort temperature (T_c) is investigated based on equation 4 by Griffiths' method when regression becomes unreliable due to narrow temperature range or small sample of votes [32, 33].

$$T_c = T + ((0 - TSV)/\propto) \quad (4)$$

where "*T*" is operative temperature or other thermal index and "$\propto$" is Griffiths' constant i.e. rate of thermal sensation change with room temperature which is used as 0.5 in this study as applied by Humphreys *et al.*, [34] at 7-point thermal sensation scale. The individual comfort temperatures are calculated by substituting all thermal sensation votes and operative temperatures in equation 4.

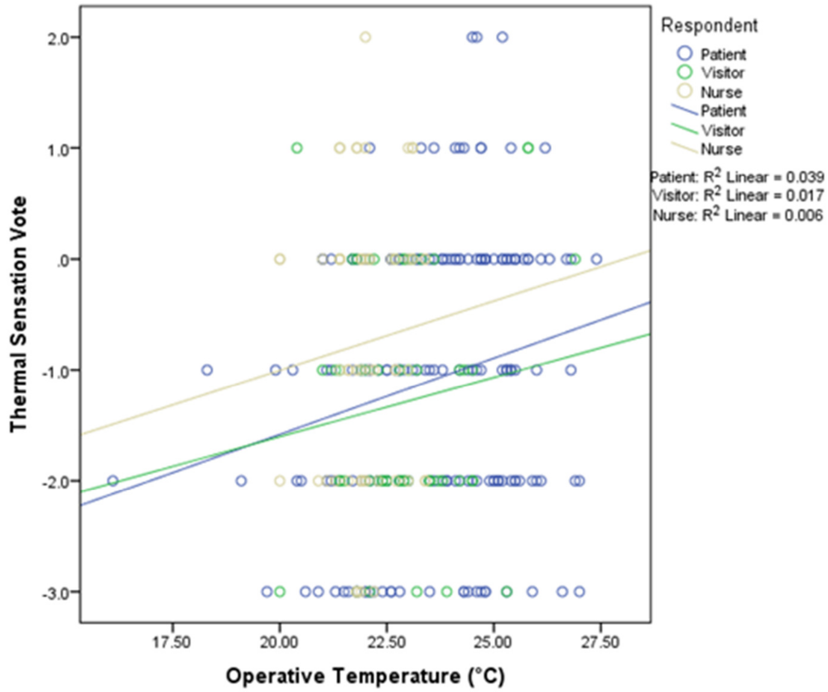

Fig. 6. Relation between *TSV* and T_{op}

3.4 Comparison of comfort temperatures by respondent type

The error bar ranges for investigated comfort temperatures through Griffiths' method by gender for different respondents are shown in Figure 7. The average comfort air temperature (T_{ca}) for patients, visitors and nurses were 25.8, 25.6 and 23.7°C. The error bars (mean ± 2S.E) of each index for each gender for patients, visitors and nurses are almost overlapping which show negligible differences between comfort temperatures by gender except error bar range for male visitors which is wider than female. The mean comfort temperatures for all respondents at their places in hospital wards are presented in Table 6. The mean comfort temperature based on operative temperature for nurses at their stations in wards was investigated as 23.5°C i.e. less than Azizpour *et al*., [17] and Yau *et al*., [16] studies for hospital staff in staff workspaces and facility department.

Whereas the mean comfort temperatures based on operative temperature for the patients and visitors in patient rooms were investigated as 25.7°C and 25.5°C. Mean comfort temperature for patients is same for indoor air temperature (T_{ca}) with S.D. as 2.7°C and other 3 thermal indices (T_{cg}, T_{cop} and T_{cmrt}) with S.D. as 2.8°C, 2.7°C and 3.1°C. The mean comfort temperatures for visitors in patient rooms for air temperature and other indices are almost same whereas for nurses at their workstations are having slight difference. The lower comfort temperatures for nurses reveal low temperature preference by them due to their high activity level and clothing insulation in accordance with their thermal preference results in this study as well as Khodakarami *et al*., [15] study in an Iranian hospital.

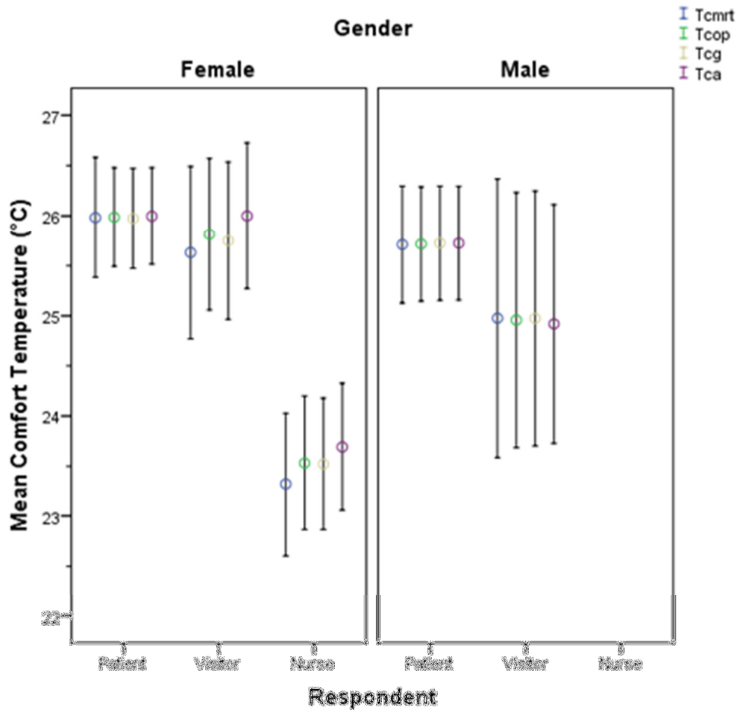

Fig. 7. Mean comfort temperatures by respondent type and gender with 95% confidence interval

Table 6
Mean Comfort temperatures for occupants in hospital ward

Respondent	T_{ca} (°C)		T_{cop} (°C)		T_{cg} (°C)		T_{cmrt} (°C)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Patient (n=200)	25.8	2.7	25.7	2.8	25.7	2.8	25.7	3.1
Visitor (n=55)	25.6	2.3	25.5	2.4	25.5	2.5	25.4	2.7
Nurse (n=60)	23.7	2.5	23.5	2.6	23.5	2.5	23.3	2.7

Note: n: Number of samples, S.D.: Standard deviation, $T_{ca:}$ Comfort air temperature, T_{cg}: Comfort globe temperature, $T_{cmrt:}$ Comfort mean radiant temperature, $T_{cop:}$ Comfort operative temperature

4. Conclusions

This study presents the results of thermal comfort studied in one private Malaysian hospital in-patient wards. More research is needed in future in Malaysian or tropical hospitals especially for multiple bed or open wards for reducing energy usage and improving the thermal comfort conditions of different ward occupants. The mean thermal sensation vote's results from patients, visitors and nurses in in hospital wards showed that rooms and nurse stations were bit overcooled. The mean thermal preference for patients was no change might be because of their thermal sensation bluntness due to unstable health conditions and no change for visitors also but towards a bit warmer. Nurses also felt slightly cold at their workstations in different wards as mean TSV was -0.7 and their thermal preference was also no change but still towards a bit cooer. All occupants i.e. patients, visitors and nurses felt air bit drier and preferred bit humid in all hospital wards. Air movement vote was found low for patients and neutral for visitors and nurses but overall air movement was acceptable for all of them as percentage for air movement acceptance was more than 91% in all hospital wards. Air, globe, operative and mean radiant temperature for patients, visitors and nurses in ward have no significant difference in expressing comfort temperature with Griffiths method. It can be concluded that any of these indices can be used for temperature setting. Comfort temperatures based on operative temperature for patients, visitors and staffs have been found as 25.9, 25.5 and 23.5°C. These can be used as design guides for local building service engineers and researchers who intend to minimize the energy usage from hospital HVAC system, improve the well-being of occupants and increase work efficiency of hospital workers.

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