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THERMAL COMFORT IN FREE RUNNING AND MECHANICALLY CONDITIONED LEARNING FACILITIES

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Abstract:
Alhough the standard for acceptable indoor conditions for comfort cooling in non-residential buildings has been established, it is still arguable whether the standard is able to satisfy every condition since thermal comfort may be influenced by various factors. Hence, this study aims to determine the suitable temperature that will maximize the thermal comfort at a given specific location, namely the learning facilities situated at Faculty of Architecture, Planning and Surveying (FSPU), Universiti Teknologi Mara, Shah Alam. The main objective of this study is to compare the comfort temperature obtained using two different methods namely Predicted Mean Vote, which is considered as an objective measurement, and Actual Mean Vote, which is considered as a subjective measurement. Physical parameters at four different learning facilities were taken. Three of the learning facilities are categorised as mechanically conditioned building and one is categorised as a free running building. A total of 109 students were surveyed. Comfort temperature for free running building in FSPU is found to be 27°C according to PMV and 27.10°C according to AMV. Whereas, the comfort temperature for mechanically conditioned building is found to be 24.10°C in accordance to PMV and 26.90°C in accordance to AMV.

Keywords: Thermal comfort; Learning facilities; Predicted mean vote; Actual mean vote; Comfort temperature

1.0 INTRODUCTION

American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) (2010) defines thermal comfort as the condition of mind that expresses satisfaction with the thermal environment. Thermal comfort is a subjective matter which may be influenced by environmental factors and personal factors. Environmental factors that influence thermal comfort are temperature, relative humidity, and wind speed. Meanwhile, the personal factors include insulation and metabolic rate. ASHRAE Standard 55 mentioned that thermal comfort condition is achieved when 80% or more of the occupants are satisfied with the temperature.

Thermal comfort is an important factor that has to be considered in designing a building and its features. The main constraint with regard to thermal comfort is that it is influenced by many factors. Huizenga et al. (2006) mentioned that there is far less data that assess occupants' satisfaction across a large number of buildings using a systematic method and using occupants' opinions as a measure of building performance is still far from standard practice. Moreover, the inconsistency of thermal comfort may be a constraint to maximize thermal comfort among building's occupants.

Even though Department of Standards Malaysia (2007) has established the standard for acceptable indoor conditions for comfort cooling in non-residential buildings, it is still arguable whether the standard is able to satisfy every condition. Karyono et. al (2014) stated that the average running temperature that a person experiences does influence the person's comfort temperature. Thus, it may differ with the standard outlined in MS 1525:2007. Additionally, Frontczak and Wargocki (2011) argued that thermal comfort may be influenced by the types of building. It was mentioned in their research that the occupants of naturally ventilated buildings may have higher tolerance towards indoor thermal conditions compared to the occupants of air-conditioning buildings. Furthermore, since Malaysia is a tropical country with warm environment, the occupants of a building may prefer a cooler indoor environment. This was supported by Djamila et. al (2014) who stated that people under warm environment prefer to feel cooler meanwhile people in cool environment prefer to feel warmer.

Therefore, the suitable range of temperature for learning facilities in FSPU should be investigated in detail. Thus, this study's aim is to determine the suitable temperature that will maximize the thermal comfort in FSPU's learning facilities by calculating the comfort temperature using PMV and AMV method and the results obtained from both methods are further assessed.

2.0 LITERATURE REVIEW

There are numerous studies which have been conducted to identify the comfort temperature of similar learning facilities which include classroom, lecture hall and laboratory. First, for comfort temperature in classroom, a research carried out by Zaki et al. (2017) mentioned that the mean comfort operative temperature for classroom in Malaysia in both free-running mode and cooling mode is at 26.8ºC and 25.6ºC respectively. In addition, Karyono et al. (2014) through their study found that the comfort temperatures for classroom in university are 24.1ºC and 24.9ºC depending on the average running temperature a person experiences. Finally, according to Karyono and Delyuzir (2016), the comfort temperature of a private school's classroom which utilises air-conditioner is identified to be 26.7ºC.

Next, there are also few previous studies which have been conducted to identify the comfort temperature in lecture halls. According to a research by Chew et al. (2015), the acceptable indoor neutral temperature for a lecture hall in Malaysia ranged between 23.9ºC to 26.0ºC with its most ideal temperature at 25.7ºC. Additionally, Pau et al. (2013) mentioned that the suitable temperature for Malaysia's lecture halls is 25.3ºC

There is a limited previous research which has been conducted to identify the comfort temperature in a laboratory. However,a research carried out by Mishra and Ramgopal (2014) in a naturally ventilated laboratory suggested that the neutral temperature in laboratory lies at 26.5 ºC. As for comparison between Predicted Mean Vote (PMV) and Actual Mean Vote (AMV), there are also numbers of studies which have been conducted to compare these two methods. Study by ter Mors (2010) conducted in primary school classrooms in Netherland found that the values of PMV and AMV differ by up to 1.5 scale point. It concludes that subjects prefer a temperature lower than the temperature predicted by PMV model. However, a study conducted by Azizpour et al (2013) found that the neutral operative temperature derived from PMV is 25 ºC. Whereas the neutral operative temperature derived from AMV is 26.6 ºC, showing 1.6 ºC temperature difference. This indicates that the actual occupants' neutral temperature is higher than predicted by PMV and closer to slightly warm sensation as referred in ASHRAE's seven point thermal comfort sensation scale. Additionally, a study by Chew et al. (2015) found that the neutral operative temperature derived from PMV was 25 ºC. Meanwhile, the neutral operative temperature derived from AMV was 25.7 ºC, indicating 0.7 ºC difference from the PMV. Hence, this study also indicates that the actual occupants' neutral temperature is higher than predicted by PMV.

3.0 METHODOLOGY

3.1 Case study

Two different types of buildings at Faculty of Architecture, Planning and Surveying, Universiti Teknologi Mara, Shah Alam are used as a case study. The types of building involved are free running and mechanically conditioned building.

3.1.1 Free running building

For free running buildings, soil laboratory is selected for the case study since it is the only free running building which is used as a classroom at the faculty.

Figure 1: Atmosphere at soil laboratory

3.1.2 Mechanically conditioned building

As for mechanically conditioned buildings, the classrooms at block C i.e. C401 and block D i.e. D105 and lecture hall are selected for the case study.

Figure 2: Atmosphere at C401

Figure 3: Atmosphere at D105

Figure 4: Atmosphere at lecture hall

3.2 Data collection

The data of this study are obtained through field research where the environment and subject are not controlled. Generally, there are two methods of data collection carried out in this study; these methods are observation and cross-sectional survey. Observation is carried out mainly to measure the physical data which include air temperature, air velocity and relative humidity using multifunction anemometer. In addition, the physical data measured are used to calculate Predicted Mean Vote and Predicted Percentage of Dissatisfied which are the objective measurement. Apart from observation, cross-sectional survey is also performed in this study in order to obtain subjective evaluation of the occupants. Data obtained from the cross-sectional survey are mainly used to calculate Actual Mean Vote which is the subjective measurement.

3.3 Objective measurement

Physical data which include air temperature, air velocity and relative humidity are obtained using multifunction anemometer through field observation. The observation is carried out during learning period in each selected location. According to ASHRAE Standard 55 (2004), air temperature and air velocity have to be measured at 0.1 m, 0.6 m and 1.1 m above floor level for seated occupants. Meanwhile, relative humidity is measured at 0.6 m above floor level for seated occupants. However, in this study, the physical data are measured at a single level which is approximately 0.8 m above floor level. The measurement is taken at three points at soil laboratory and four points at each classroom located at block C and block D. Meanwhile, at Dewan Kuliah, the measurement is taken at nine points. The average air temperature, air velocity and relative humidity are calculated for each location. From the physical data measured, the Predicted Mean Vote and Predicted Percentage of Dissatisfied for each location are calculated. In addition, the metabolic rate is estimated to be at 1.2 met which represents activity of sitting and writing. Meanwhile the clothing value is estimated to be 0.57 clo which represents shirt, trouser, underwear, sock and shoe. PMV and PPD are calculated using these formula:

$$PMV = (0.303e^{-2.100*M} + 0.028) * [(M - W) - H - Ec - Cres - Eres]$$

$$PPD = 100 - 95e^{[-(0.3353PMV^4 + 0.2179PMV^2)]}$$

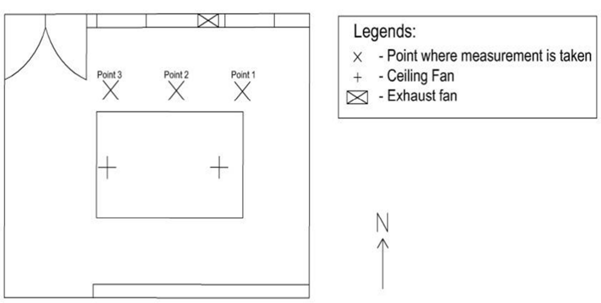

Figure 5: Instrument layout in soil lab

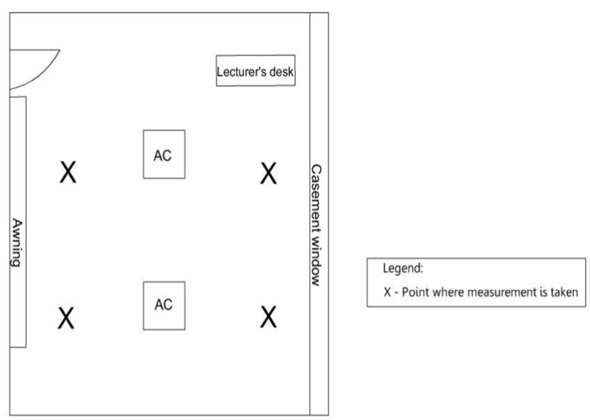

Figure 6: Instrument layout in C401

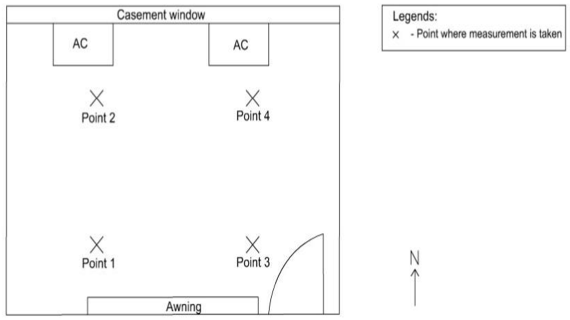

Figure 7: Instrument layout in D105

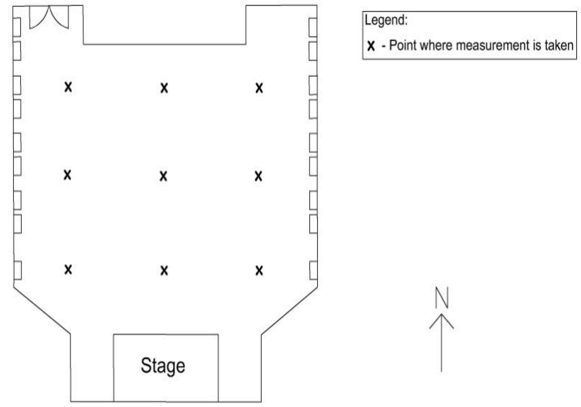

Figure 8: Instrument layout in lecture hall

3.4 Subjective measurement

Since this study focuses on students's comfort as a subjective measurement, 109 students were surveyed using a set of questionnaire which includes demographic information, thermal sensation, thermal preference, sweat rate, air movement and overall comfort level. The thermal sensation vote is constructed based on ASHRAE's seven points thermal comfort sensation scale. Hence, by assessing the thermal sensation vote voted by occupants the actual mean vote is calculated.

Table 1: Thermal sensation vote on the 7-point ASHRAE scale

Scale	Sensation
-3	Cold
-2	Cool
-1	Slightly cool
0	Neutral
+1	Slightly warm
+2	Warm
+3	Hot

4.0 ANALYSIS AND FINDINGS

4.1 Data on respondents

Table 2: Data on respondents

Type of building	Gender		Descriptive statistic	Age (years)	Height (cm)	Weight (kg)	Estimated clothing value
	Male	Female					
Free running building	18	22	Total	878	6485	2309	0.57
			Minimum	21	150	40	
			Maximum	25	178	82	
			Mean	22	162.1	57.7	
Mechanically conditioned building	36	33	Total	1628	11272	4331	0.57
			Minimum	23	150	38	
			Maximum	30	183	118	
			Mean	23.6	163.4	62.8	
Total	54	55					

Respondents involved in this study are students who used the classrooms in FSPU. The students are engaged in light activities which include sitting and writing as the questionnaire is distributed. Overall, there are 109 respondents. 40 respondents are those who occupied a free running building which is the soil lab and 69 respondents are those who occupied mechanically conditioned buildings which include two classrooms at block C and block D respectively and a lecture hall (Dewan Kuliah).

4.2 Free running building

Table 3: Physical parameters measured at free running building

Date	Time	Point	Air temperature (°C)	Relative humidity (%)	Air velocity (m/s)
22nd March	2.15pm	1	31.30	61.30	0.9
		2	31.30	62.50	1.9
		3	31.30	63.90	1.1
		Mean	31.30	62.60	1.3
23rd March	3.15pm	1	30.90	64.30	1.0
		2	31.00	64.20	2.0
		3	31.00	63.50	1.3
		Mean	31.00	64.0	1.4
26th March	4.00pm	1	28.70	76.90	0.9
		2	28.30	78.10	1.8
		3	28.50	76.90	1.0
		Mean	28.50	77.30	1.2

For free running buildings, field measurement is carried out only at one location which is the soil lab. Hence, the measurements are taken at three different dates together with different subjects.

4.2.1 Objective measurement

Table 4: PMV and PPD for free running building

Date	Mean temperature (°C)	Mean relative humidity (%)	Mean air velocity (m/s)	Predicted Mean Vote	Predicted Percentage of Dissatisfied (%)
22nd March	31.30	62.60	1.3	+0.97	25
23rd March	31.00	64.0	1.4	+0.87	21
26th March	28.50	77.30	1.2	+0.33	7

By using objective measurement, the highest PMV and PPD calculated are +0.97 and 25% respectively which was on 22nd March where the temperature was recorded at 31.30°C. Second highest was on 23rd

March where the air temperature was measured at 31.00°C. PMV and PPD calculated on that date was +0.87 and 21% respectively. Hence, PMV on both days is higher than the comfort range suggested by Fanger's model which ranges between -0.5 to +0.5. However, on 26th March where the measured temperature was at 28.50°C, the calculated value of PMV and PPD are at +0.33 and 7% respectively, which is within the comfort range suggested in Fanger's model.

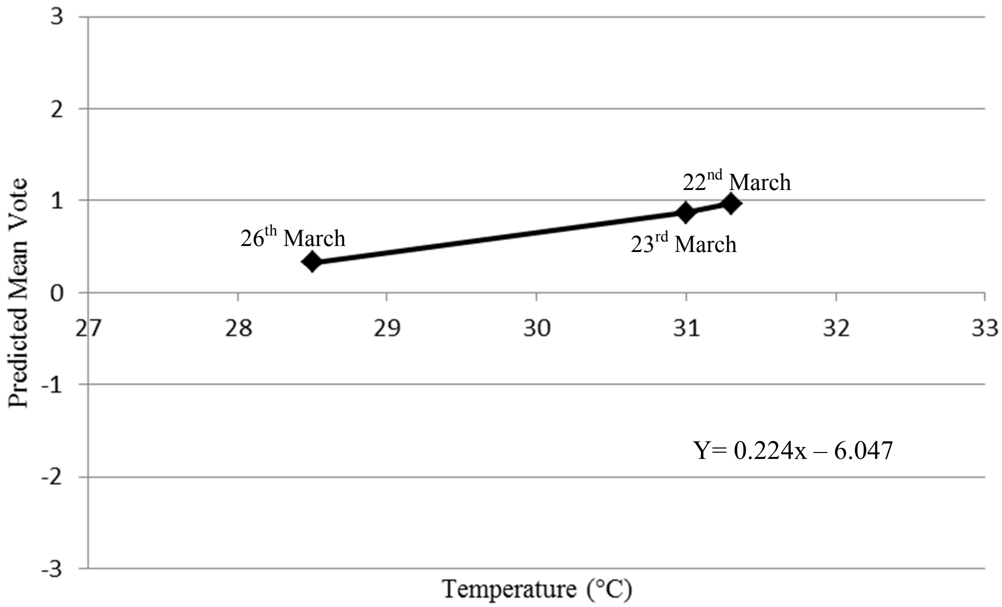

Figure 9: Linear regression on PMV with air temperature for free running building

Figure 9 shows the linear regression on PMV with air temperature. By analysing the linear regression, it produces an equation of Y= 0.224x – 6.047. Hence, from this equation, the neutral temperature where Y=0 is found to be 27.00°C. In addition, the comfort range where Y= -0.5 and +0.5, the comfort temperature is found to range between 24.76°C to 29.23°C.

4.2.2 Subjective measurement

Table 5: AMV for free running building

Date	Mean temperature (°C)	Number of subject	TSV on ASHRAE scale							Actual Mean Vote
			Cold = -3	Cool = -2	Slightly cool = -1	Neutral = 0	Slightly warm = +1	Warm = +2	Hot = +3	
22nd March	31.30	15	0	2	0	5	3	2	3	+0.80
23rd March	31.00	15	0	0	2	1	6	6	0	+1.07
26th March	28.50	10	0	0	0	8	1	1	0	+0.30

By using Actual Mean Vote that is calculated based on the data obtained through questionnaire, the result somehow found to be inconsistent as compared to the result of PMV. This is due to the fact that thermal comfort may be influenced by personal factors. For the survey conducted on 22nd March where the air temperature was recorded at 31.30°C, the AMV is +0.80. This is indeed lower compared to the AMV on 23rd March although the air temperature on 23rd March was slightly lower. However, the AMV on both days are higher than the comfort range as suggested in Fanger's model. Additionally, the AMV on 26th

March where the air temperature was at 28.50°C is +0.30, which is within the comfort range as suggested in Fanger's model.

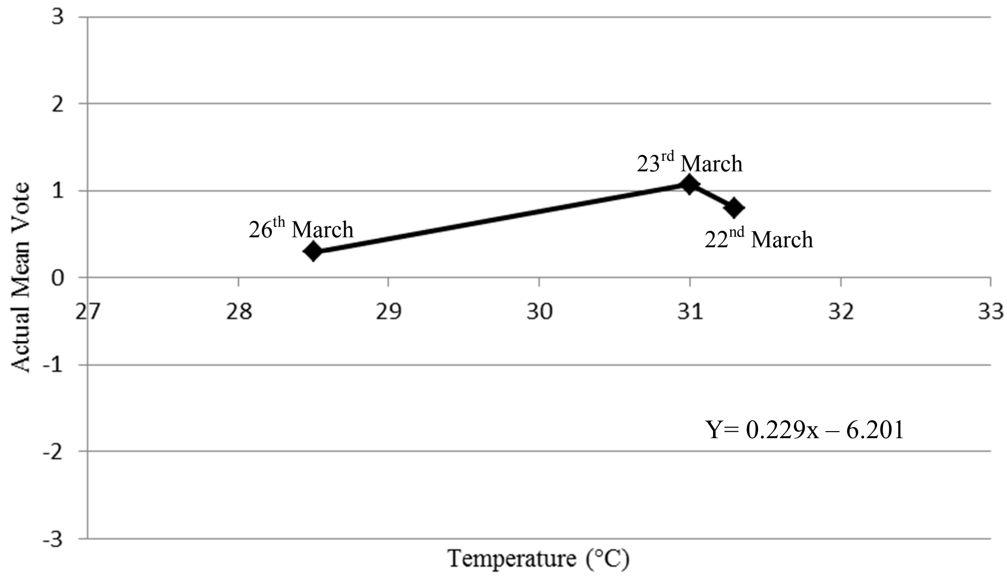

Figure 10: Linear regression on AMV with air temperature for free running building

Figure 10 shows the linear regression on AMV with air temperature. By referring to the linear regression, it produces an equation of Y= 0.229x – 6.201. Hence, from this equation, the neutral temperature in where Y=0 is found to be 27.10°C. Additionally, based on AMV method, the comfort range is found to be between 24.90°C to 29.26°C.

4.2.3 Correlation between objective and subjective measurement

Based on table 6, the neutral temperature as estimated by PMV is 27.00°C. Whereby, the neutral temperature in accordance to AMV is 27.10°C. This indicates that PMV slightly underestimates the neutral temperature by 0.10°C. As for the comfort range, the comfort range based on PMV is found to be between 24.76°C to 29.23°C. Whereas, the comfort range based on AMV is found to range within 24.90°C to 29.26°C.

Table 6: Neutral temperature and comfort range in free running building based on PMV and AMV

Date	Predicted Mean Vote	Actual Mean Vote	Regression equation		Neutral temperature (°C)		Comfort range (°C)	
			PMV	AMV	PMV	AMV	PMV	AMV
22nd March	0.97	0.80	Y= 0.224x – 6.047	Y= 0.229x – 6.201	27.00	27.10	24.76 to 29.23	24.90 to 29.26
23rd March	0.87	1.07						
26th March	0.33	0.30						

4.3 Mechanically conditioned building

For mechanically conditioned buildings, the field measurement was taken at three different locations which utilised air-conditioners. The subjects at each location differ from one another. The air velocity in mechanically conditioned buildings is below 0.1m/s and it is unable to be measured using anemometer which can measure a minimum of 0.1m/s air velocity. Thus, the air velocity in mechanically conditioned buildings is not measured.

Table 7: Physical parameters measured at mechanically conditioned building

Location	Date	Time	Point	Air temperature (°C)	Relative humidity (%)
C401	28th March	8.30am	1	24.5	59.60
			2	24.4	60.40
			3	25.0	61.30
			4	25.1	62.40
			Mean	24.8	60.90
D105	30th March	11.30am	1	25.70	56.20
			2	25.90	57.90
			3	25.60	55.50
			4	25.80	55.00
			Mean	25.80	56.20
Lecture hall	29th March	9.30am	1	26.80	68.40
			2	26.80	68.40
			3	26.80	68.60
			4	27.10	68.70
			5	27.10	68.40
			6	27.20	68.20
			7	27.10	68.60
			8	27.20	68.60
			9	27.10	68.90
			Mean	27.00	68.50

4.3.1 Objective measurement

The highest PMV and PPD calculated is at the lecture hall where the measured temperature was at 27.00°C which is the highest temperature compared to the other locations. Calculated PMV and PPD at the lecture hall are +0.99 and 26% respectively. The second highest calculated PMV and PPD are at D105 where the air temperature was measured at 25.80°C. Calculated PMV and PPD at D105 are +0.53 and 11% respectively. PMV for both lecture hall and D105 exceed the comfort range as suggested in Fanger’s model which is +0.5. However, the calculated PMV at C401 where the air temperature was measured at 24.80°C is found to be +0.27 which is within the comfort range stated in Fanger’s model. Additionally, the calculated PPD at C401 is 7%.

Table 8: PMV and PPD for mechanically conditioned building

Location	Mean temperature (°C)	Mean relative humidity (%)	Predicted Mean Vote	Predicted Percentage of Dissatisfied (%)
C401	24.80	60.90	+0.27	7
D105	25.80	56.20	+0.53	11
Lecture hall	27.00	68.50	+0.99	26

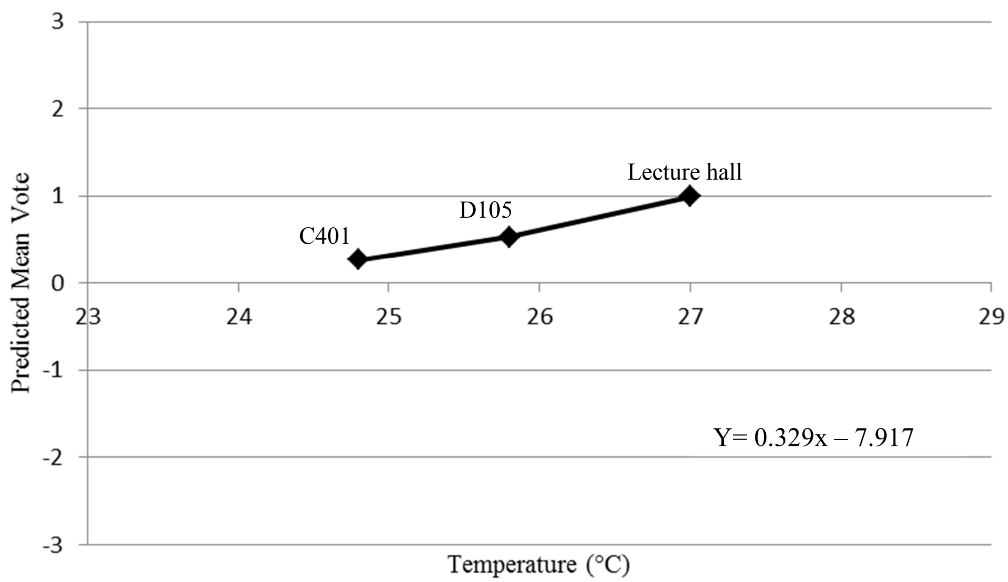

Figure 11: Linear regression on PMV with air temperature for mechanically conditioned building

Figure 11 shows the linear regression on PMV with air temperature at mechanically conditioned buildings. By analysing the linear regression, it produces an equation of Y= 0.329x – 7.917. Thus, using this equation, the neutral temperature where Y=0 is found to be 24.1°C. Whereas, the comfort range in which the value of Y= -5 and +5, the range of comfort temperature is found to be between 22.54°C to 25.58°C.

4.3.2 Subjective measurement

Table 9 shows the results obtained using AMV show a significant difference compared to the result obtained using PMV.

Table 9: AMV for mechanically conditioned building

Location	Mean temperature (°C)	Number of subject	TSV on ASHRAE scale							Actual Mean Vote
			Cold = -3	Cool = -2	Slightly cool = -1	Neutral = 0	Slightly warm = +1	Warm = +2	Hot = +3	
C401	24.80	21	2	1	8	6	2	0	2	-0.38
D105	25.80	23	1	3	8	10	0	1	0	-0.65
Lecture hall	27.00	25	0	2	5	10	5	1	2	+0.16

The highest calculated AMV is +0.16 which is at the lecture hall where the air temperature was measured at 27.00°C. The result is within the comfort range as suggested in Fanger's model. As for the AMV at C401 and D105, the AMV calculated is below 0 which indicates that the subjects experiences a slightly cool sensation. The AMV at C401 where the air temperature was measured at 24.80°C is -0.38. Though the air temperature at D105 is 1°C higher compared to the air temperature at C401, the AMV calculated for D105 is lower compared to the AMV for C401. This may be due to the fact that personal factors influenced thermal comfort. The calculated AMV for D105 is -0.65, which is below the comfort range suggested in Fanger's model.

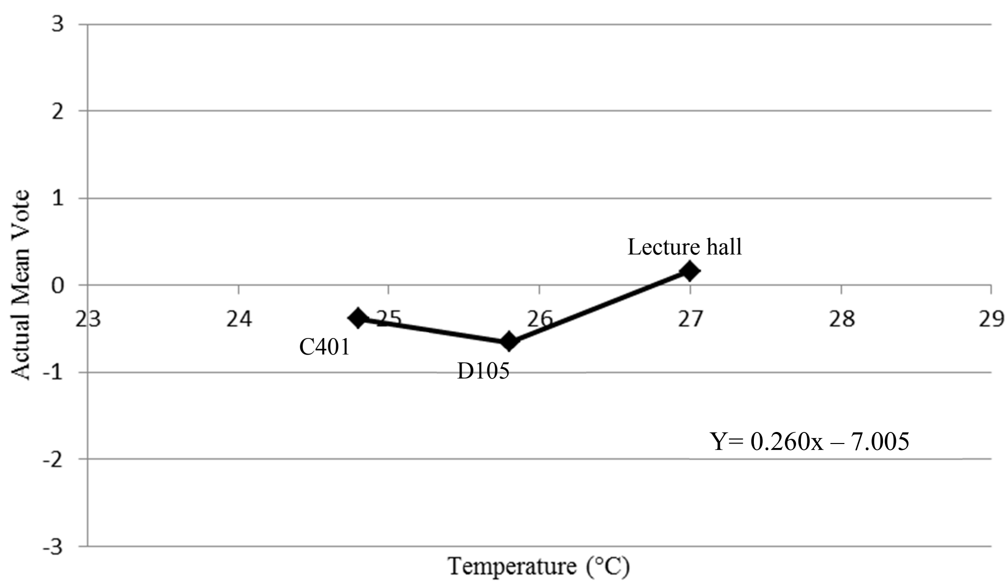

Figure 12: Linear regression on AMV with air temperature for mechanically conditioned building

Figure 12 shows the linear regression on AMV with air temperature at mechanically conditioned buildings. The linear regression produces an equation of Y= 0.260x – 7.005. Hence, from this equation, the neutral temperature in accordance to AMV is found to be 26.9°C. Whereas, the comfort range based on AMV is found to be between 25.02°C to 28.87°C.

4.3.3 Correlation between objective and subjective measurement

Based on table 10, the neutral temperature derived from the PMV regression equation is equal to 24.1°C. Whereas, the neutral temperature obtained from AMV regression equation is 26.9°C. This indicates that PMV underestimates the neutral temperature by 2.8°C. As for the comfort range, according to PMV regression equation the comfort range lies between 22.54°C to 25.58°C. Meanwhile, based on AMV regression equation the comfort range ranged between 25.02°C to 28.87°C.

Table 10: Neutral temperature and comfort range in mechanically conditioned building based on PMV and AMV

Location	Predicted Mean Vote	Actual Mean Vote	Regression equation		Neutral temperature (°C)		Comfort range (°C)	
			PMV	AMV	PMV	AMV	PMV	AMV
C401	+0.27	-0.38	Y= 0.329x – 7.917	Y= 0.260x – 7.005	24.1° C	26.9°C	22.54° C to 25.58° C	25.02° C to 28.87° C
D105	+0.53	-0.65						
Lecture hall	+0.99	+0.16						

4.4 Sensation preference

Table 11: Sensation preference in free running building

Date	Number of subject	Sensation preference		
		Slightly cool	Neutral	Slightly warm
22nd March	15	1	14	0
23rd March	15	7	6	2
26th March	10	2	7	1
	Total	10	27	3

Table 12: Sensation preference in mechanically conditioned building

Location	Number of subject	Preference		
		Slightly cool	Neutral	Slightly warm
C401	21	3	18	0
D105	23	10	13	0
Lecture hall	25	15	9	1
	Total	28	40	1

By referring to Table 11 and Table 12, a majority of the subjects prefer a neutral sensation. Up to 58% and 67.5% of the subjects voted to prefer a neutral temperature in both free running and mechanically conditioned buildings respectively.

5.0 CONCLUSION

In this study, the comparison between comfort temperature as predicted by PMV and calculated by AMV is successfully established. In free running buildings, PMV predicted the neutral temperature to be 27.00°C. Whereas, by using AMV the neutral temperature is found to be 27.10°C which is 0.10°C higher than predicted by PMV. Hence, the slight difference of neutral temperature between these two methods indicates that PMV method may be used to determine the comfort temperature for free running buildings in FSPU. However, as for mechanically conditioned buildings, PMV predicted the neutral temperature to be at 24.1°C. On the other hand, based on AMV, the neutral temperature is found to be 26.9°C, indicating a difference of 2.8°C . The significant difference of neutral temperature between PMV and AMV methods indicates that PMV is not suitable to be used to determine the comfort temperature for mechanically conditioned buildings in FSPU.

Alhough previous studies suggested that occupants of buildings in warm climate may prefer a slightly cool sensation, this study found that majority of occupants in both free running and mechanically conditioned buildings prefer a neutral sensation. As for the air temperature at FSPU's learning facilities, actions need to be taken to meet the neutral temperature in order to provide a comfortable learning environment. For free running buildings, the air temperature ranged between 28.50°C to 31.30°C. Whereas, the neutral temperature based on AMV is 27.10°C. Hence, the occupants might experience a slightly warm sensation. Thus, the temperature should be reduced to meet the neutral temperature. As for mechanically conditioned building swhere the temperature ranged between 24.80°C to 27.00°C, it can be concluded that only the air temperature at lecture hall is close to the neutral temperature which is 26.90°C. However, the air temperature at C401 and D105 is lower compared to the neutral temperature. Thus, temperature at both C401 and D105 can be increased. This will not only provide comfort to the occupants but will also aid in reducing electricity's expenditure.

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