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Thermal Comfort Assessment of UPM Engineering Library in Tropical Climate Conditions

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ABSTRACT

Thermal comfort is the study of indoor comfort level feel by the occupant in a room. This paper presents the study of thermal comfort that had been carried out in the library of engineering faculty at Universiti Putra Malayia in Serdang, Malaysia. The study was made in 4 days from 9 am to 11 am on October and November. This study was carried out to assess their thermal conditions during the occupants' study hours. Thermal comfort variables were measured during study hours too. Qualitative and Quantitative data analysis showed that engineering library meet the requirement of comfort zone thermal conditions of ASHRAE standard 55 and ISO 7730. The result shows the environmental condition of the library is neutral to slightly warm in 4-point ASHRAE scale. The linear regression between Predicted Mean Vote and Operative Temperature reveals that the maximum acceptable temperature in this field of study is 26.5ºC.

1. Introduction

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) describes "thermal comfort" as a condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation [1]. The subjective assessment of thermal comfort is impacted not only by the thermal environment and personal variables that influence heat transfer with this environment, but also by psychological elements that directly influence a person's state of mind [2]. Poor thermal comfort can be caused by a number of environmental factors, including heat from electrical lighting, a lack of proper ventilation, high humidity levels, and poorly performing building covers. Thermal comfort is an essential component of the quality of interior environments. Studies done in the past [3–10] suggested that thermal comfort does have an effect on both productivity and learning. The temperature of the air, the air movement, the humidity, and the velocity in a library all influence how an occupant feels about the thermal comfort of the space. The clothing they wore to study, the quantity of physical work activity done in the library, and the

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mean radiant temperature, including the radiant temperature of the walls, floor, and windows were all factors. There has been a substantial amount of research carried out on the topic of thermal comfort in the hot and humid environment of Malaysia, using the climatic conditions of the Malaysian tropic as case studies. Shaari carried out a study on thermal comfort in an air-conditioned university classroom at the Universiti Teknologi Malaysia (UTM) in Kuala Lumpur. He discovered that as a result of the investigated adaption methods, the majority of the students have a tendency to adjust the thermostat for the air-conditioning. There was not a single instance in which the temperature in the classroom fell within the ASHRAE-defined comfort zone [11].

Kannan also performed an airflow thermal comfort simulation study in wind-ventilated classrooms in Malaysia [12]. They simulate thermal comfort in an academic institution and recommend a hypothetical simulation to improve the ventilation of uncomfortable room. Mechanical ventilation systems in tertiary institutions have been widely served to maintain a comfortable and healthy environment for staff and students to work and study. Cheong proposed recommendation to improve the air-conditioned thermal comfort of tertiary lecture theatre in the tropical buildings through monitoring indoor air quality audit such as carbon dioxide, carbon monoxide and total volatile organic compounds as well as investigating air exchange rate, ventilation effectiveness [13]. Another study by Kwong in tropical educational buildings were done to identify the thermal perception of an enclosed transitional space [14]. A comprehensive review on thermal comfort studies in Malaysia and neighbored regions listed in a table by Daghigh shows that thermal comfort range is higher than expected by international standards for hot-humid climate [15]. A field study on the environmental conditions and occupant comfort was carried out in two schools, and in a public waiting area in a health clinic in Johor Bahru. It showed that the occupants in the tropic environment such as Malaysia have a higher heat tolerance and can adapt to the environment [16].

The principal goals of this research project are to evaluate the indoor climate of a mechanically ventilated library located in the Engineering Faculty of Universiti Putra Malaysia and to determine the degree of thermal comfort that people experience inside of buildings located in tropical areas. The methods, data, and findings of this investigation are presented in this research

2. Methodology

2.1 Field of Study

The research was carried out in the library in Faculty of Engineering, UPM as in Figure 1.

Fig. 1. Engineering Faculty library of UPM

2.2 Library Setup

Based on ASHRAE standard 55 (2004), measurements of chosen thermal environment parameters were collected. These measurements were conducted at 1.1 meters above the floor level and related to human thermal balance at four separate measuring locations, as illustrated in Figure 2. One point was selected as the primary measurement aim, and three more points were selected as control points in order to increase the level of control over the measuring process.

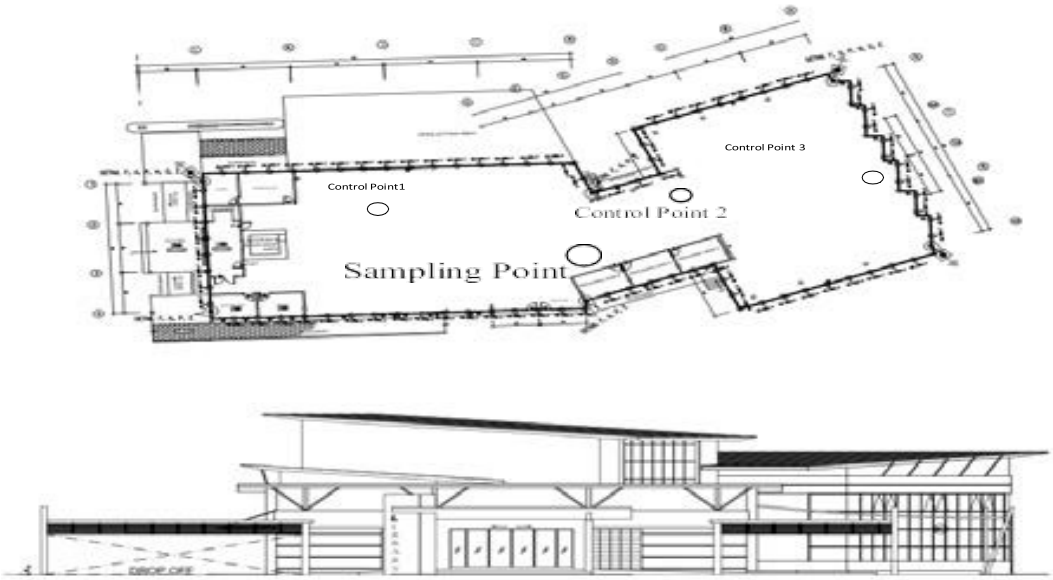

Fig. 2. Layout of Engineering Library and Measuring Points

In this investigation, measurements of thermal comfort and indoor air quality (IAQ) are taken at the busiest times of the day for a total of four days, with each day consisting of two hours broken up into 15-minute intervals. In reference to the time of measurement, October 2017 is taken into consideration.

2.3 Quantitative Data Collection

The result of the measurement is an objective statement regarding the level of thermal comfort that has been achieved. Parameters such as air ambient temperature, relative humidity, radiation temperature, airflow velocity, and air quality index such as carbon monoxide level and carbon dioxide level are gathered. As can be seen in Figures 3 and Figure 4, a device with the model number PHB-318 is utilized in the process of measuring both the temperature and the relative humidity of the air.

Figure 4 TSI's VELOCICALC® Air Velocity Meters, Models 8345 and 8346 measure velocity and temperature, calculate flowrate, perform multi-value averaging, and determine minimum and maximum readings. The YES AIR is a battery powered, portable air quality detection and data logging instrument designed for intermittent or continuous indoor air quality monitoring (Figure 5). The mean radiant temperature is a significant factor, the equation for the calculation of Mean Radiant Temperature. Two more input values for PMV are clothing index and activity, clothing influences a person's heat balance. It constitutes the boundary layer between body and indoor climate and therefore has a direct impact on thermal comfort. In this study, all of the respondents (students, staff, and visitors) are sitting in the library for seated activity during the field measurement. As per standard ISO7730, 2005, the metabolic rate for seated activity is 1.1 met or 63.8 W/m2 which is sedentary activity (laboratory, school, office, and dwelling). In addition, the clo-value according to

ISO 7730, 2005 is set to be 0.5 clo where males were wearing underpants, shirt with short sleeves, light trousers, light socks and shoes. In addition to, females were wearing panties, petticoat, stockings, dress and shoes.

Fig. 3. Indoor Air Quality Meter

Fig. 4. Air temperature meter

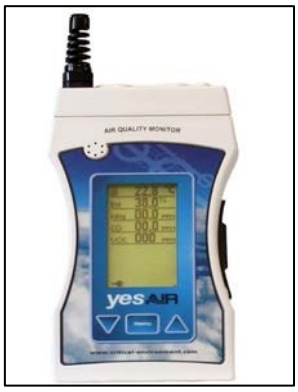

Fig. 5. Air speed meter

2.4 Qualitative Data Collection

To investigate the qualitative research questions and hypotheses about adopting thermal comfort by the practitioners in the library in UPM's faculty of engineering, a quantitative survey approach has been adopted. The Indoor Environment Quality (IEQ) Questionnaire was distributed to 46 respondents. The persons were asked to fill up the question must to have seated at least 20 minutes after entering to the library to give time to adjust library environment conditions. A pilot study was conducted to test the questionnaire for reliability. Six respondents with similar characteristics to the research sample who were not part of the main study were interviewed. Following the pilot study, some ambiguous questions were rephrased to give greater clarity and some questions were discarded, as they proved irrelevant. The purpose of this questionnaire is to try and determine how much influence each of the thermal comfort and indoor air quality parameters have on perceived IEQ in Engineering library in UPM.

3. Results

This research tended to focus on the qualitative and quantitative data that represent the acceptability of thermal comfort based on measuring and analysis data collected in the engineering library.

3.1 Quantitative Measurement

Summary of statistical indoor climate data shown below Table 1

Table 1
Summary of statistical indoor climate data thermal indoor

Thermal Indoor Parameter	Statistics	Day 1	Day 2	Day 3	Day 4
Air Temperature (°C)	Maximum	27.4	26.8	25.9	28
	Minimum	24.9	25.7	24.3	26.2
	Average	25.8	26.17	24.8	27.1
Relative Humidity (%)	Maximum	48.9	53.5	47.5	58
	Minimum	47.2	50.1	46.2	55.7
	Average	48.4	52.02	46.7	56.15
Air Velocity (m/s)	Maximum	0.15	0.13	0.13	0.18
	Minimum	0.10	0.10	0.10	0.15
	Average	0.11	0.11	0.11	0.16
Mean Radiant Temperature (°C)	Maximum	27.3	26.5	25.1	28
	Minimum	24.5	25.5	23.7	26
	Average	25.53	25.85	24.3	26.8
Carbon Dioxide (ppm)	Maximum	1345	1365	1345	1280
	Minimum	985	1240	1240	1150
	Average	1304	1328	1325	1328
Carbon Mono Oxide (ppm)	Maximum	1	3	2	2
	Minimum	0.1	1	0	1
	Average	0.7	2.3	1.1	1.5

The graph in Figure 6 depicts the temperature of the air versus the passage of time for the area being measured over the course of four days. The Engineering library has a range of air temperatures on the first day, with the maximum air temperature being 28 degrees Celsius, the lowest air temperature being 24.3 degrees Celsius, and the average air temperature being 25.8 degrees Celsius. The mean air temperature for the second day is 26.17 degrees Celsius, while the mean air temperature for the third day is 24.8 degrees Celsius, and the mean air temperature for the fourth day is still quite near to each other at 27.1 degrees Celsius. Because of this, the average air temperature for each day in the Engineering library is somewhere within the ranges of 24.8 °C and 27.1 °C, and the mean air temperature among those 4 days is 25.9 °C. It is clear from looking at the graph that the typical air temperature for each day is rather near to the acceptable temperature mean, which is roughly 24.5 degrees Celsius (ISO 7730, 2005). According to what is shown in Figure 7, the relative humidity ranges anywhere from 46.2% to 58% on any given day.

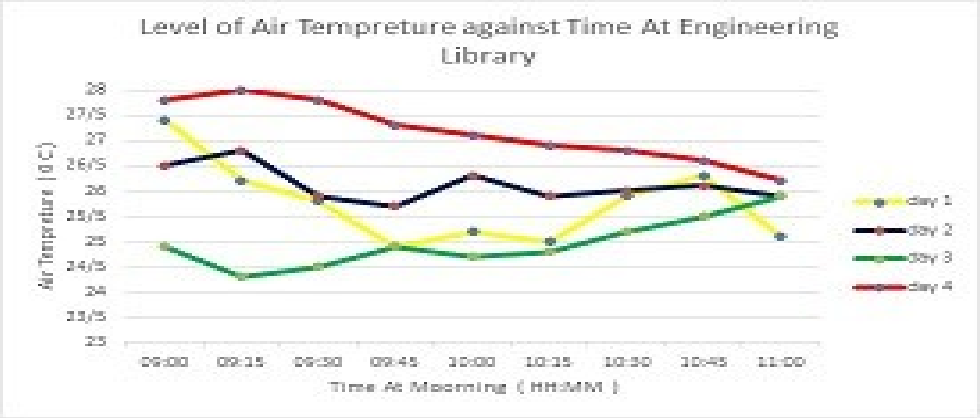

Fig. 6. Level of air temperature

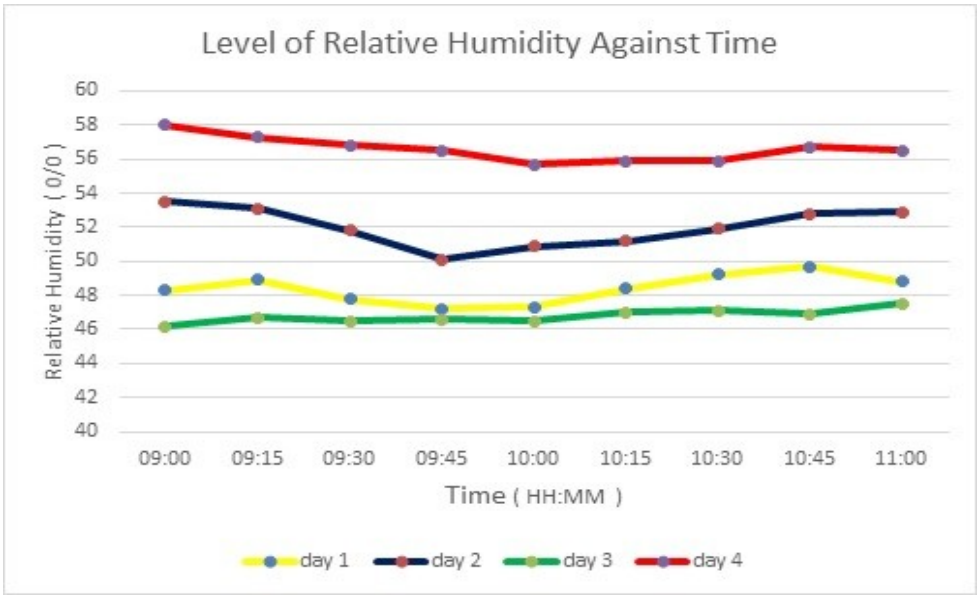

Fig. 7. Level of relative humidity

Figure 8 represents the average air velocity for days 1, 2, 3 are 0.11 m/s and for day 4 is 0.16 m/s. Therefore, the average air velocity is 0.122 m/s for these 4 days and the average air velocity for each day is between ranges of 0.10 m/s to 0.18 m/s. According to the winter and summer comfort zone issued by ASHRAE in 1997, winter indoor wind speed is maintained at 0.15 m/s, summer indoor wind speed is maintained at 0.25 m/s, the summer indoor acceptable temperature is at 23 °c -26.5 °c. Figure 9 shows the fluctuation of mean radiant temperature against time for 4 days field of measurement. The lowest mean radiant temperature in the Engineering library is 23.7 °C in day 3 while the highest mean radiant temperature is 28 °c in day 4. The average of mean Radiant Temperature for day 1 is 25.52 °C for day 2 is 25.85 °C for day 3 is 24.3 °C and for day 4 is 26.8 °C. Therefore, the average mean radiant temperature for each day in the Engineering library is between the ranges of 23.7 °C to 28 °C. As the mean radiant temperature should be kept near the air temperature but not more than 3°C below it, otherwise conditions are sensed as “stuffy”.

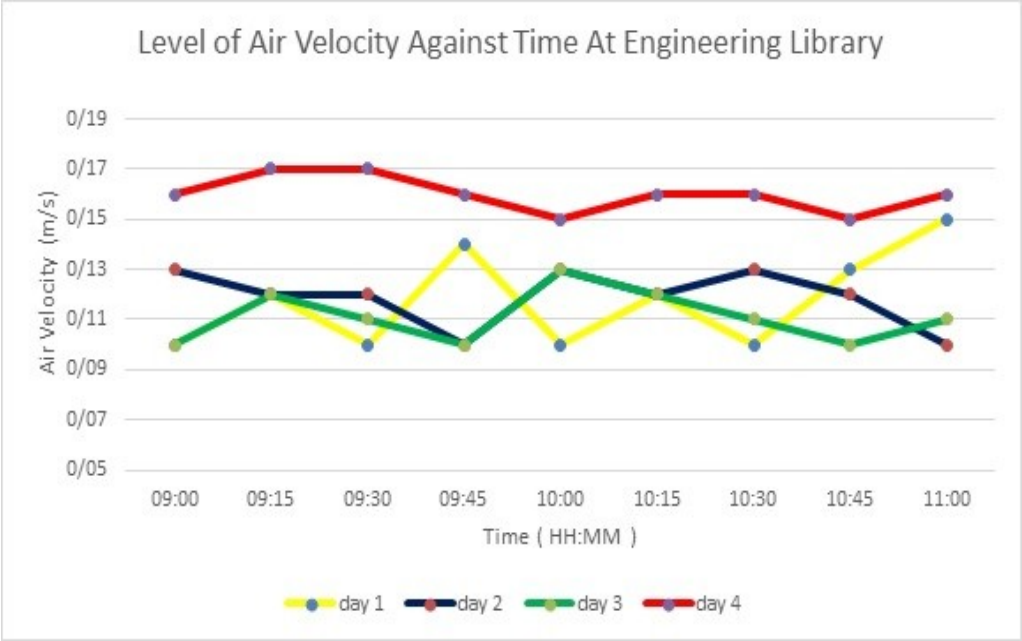

Fig. 8. Level of air velocity

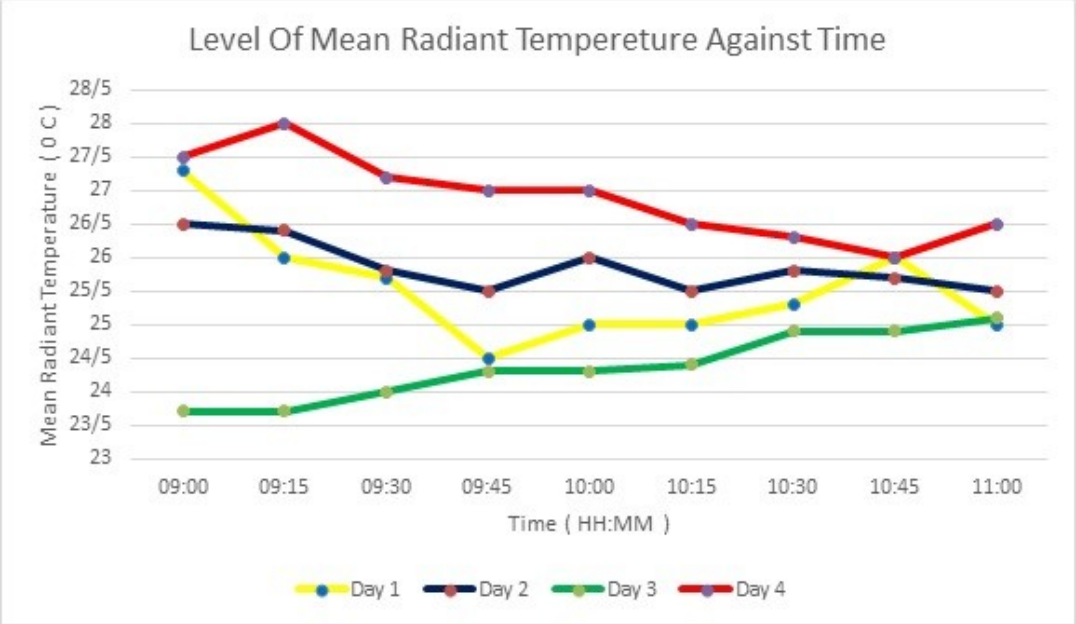

Fig. 9. Level of mean radiant

In General, ventilation rates should keep carbon dioxide concentration blow 1000 ppm to create indoor air quality condition acceptable to most individuals, but from Figure 10, it shows that the most of the measured values for the level of CO_2 in the Engineering library are more than 1000 ppm. In Figure 11, the highest level of carbon monoxide is 3 ppm in the Engineering library, while the lowest level of carbon monoxide is 0 ppm, and the average level of carbon monoxide is

0.7 ppm in the first day. The Level of carbon monoxide for 2nd day is 2.3ppm for day 3 is 1.1 ppm and for day 4 is 1.5ppm. Therefore, the average level of carbon monoxide for each day in the Engineering library is between the ranges of 0 ppm to 3 ppm, therefore level of carbon dioxide in the Engineering library is considered in acceptable range that can check in below table, which shows the safe level of carbon dioxide measurement in 4 days.

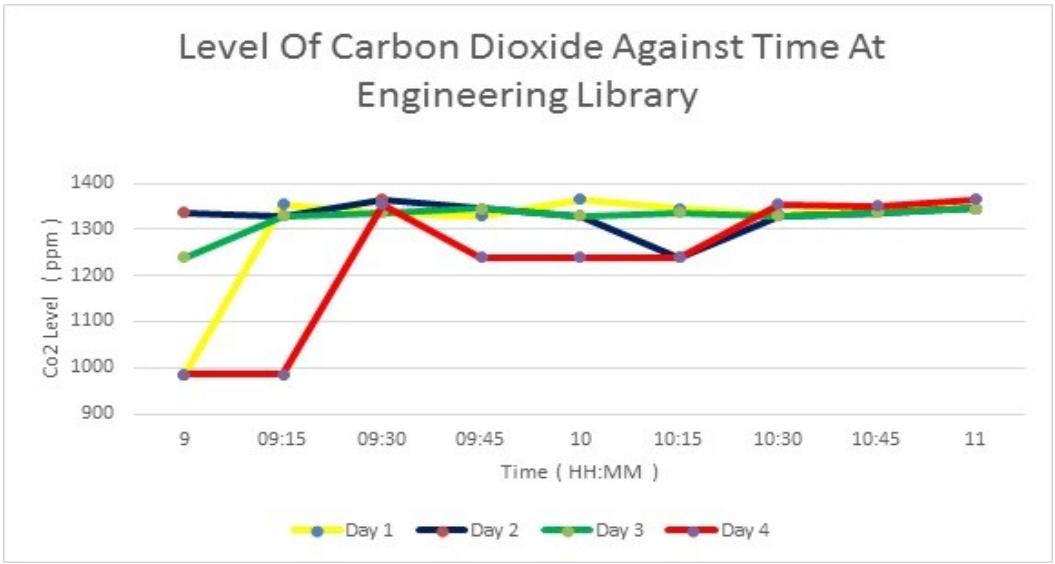

Fig. 10. Level of CO_2

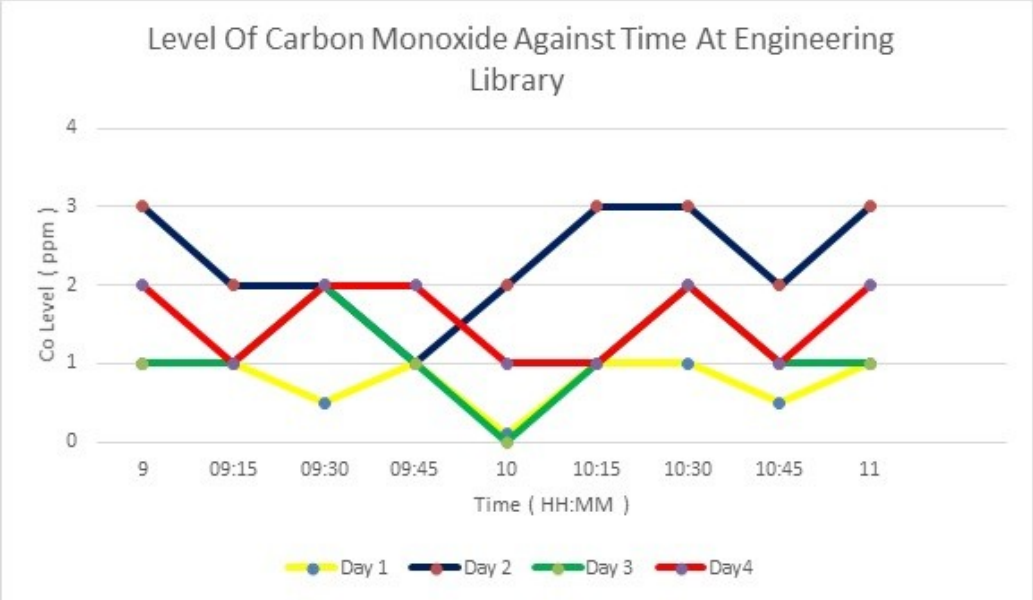

Fig. 11. Carbon Monoxide

3.2 Qualitative Measurement

Qualitative measurement was recorded using questionnaire. As it tabulated in Table 2, there are 46 samples size subject within this survey.

Table 2
Qualitative measurement for PMV

Total number of sample	46			
Gender	Male		Female	
	22		24	
Percentage	47.8 %		52.2 %	
Age	19 - 29 years (19)	30 – 40 years (25)		Above 40 years (2)
Activity	Seated Activity		Metabolic rate 1.1 Met	
Clothing Level	Trousers and T- shirt		Thermal insulation 0.5 Clo	
Nationality	Malaysian	23	Non-Malaysian	23

Figure 12 shows the qualitative measurement of air temperature in the Engineering library. The responders vote the air temperature to be cool 11% and vote to be slightly cool 20% while the 35% responders feel neutral and 25% slightly warm and 9% feels warm. This shows that performance of Air condition system in the Engineering library is acceptable because most of people voted Neutral and feel comfortable therefore the temperature is normal which is in the range of people can accept. The result of the vote match with the data of air temperature of field measurement. The bare chart at Figure 13 shows overall thermal comfort in the Engineering library. Only 1 responder (2%) vote overall very uncomfortable and just 8 responders (17%) cannot accept thermal comfort in the Engineering library. On the other hand, there are 37 responders, which accounted for 81% of the total vote as comfortable with the overall thermal comfort in the Engineering library.

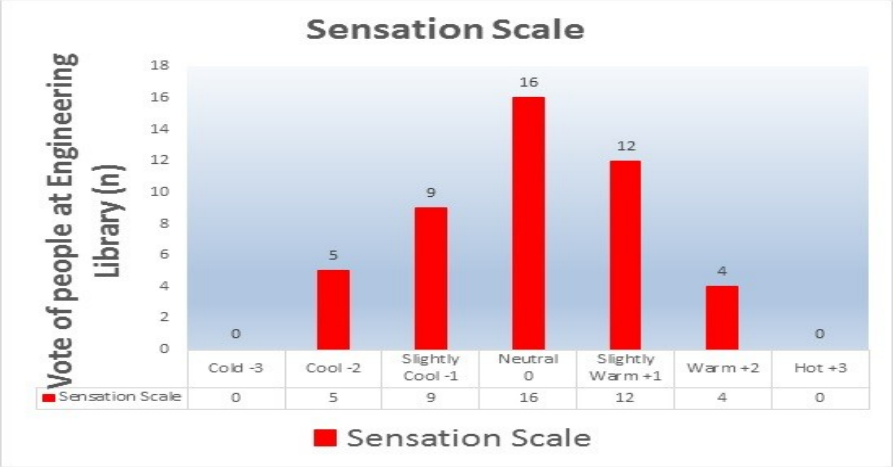

Fig. 12. Qualitative measurement of air temperature

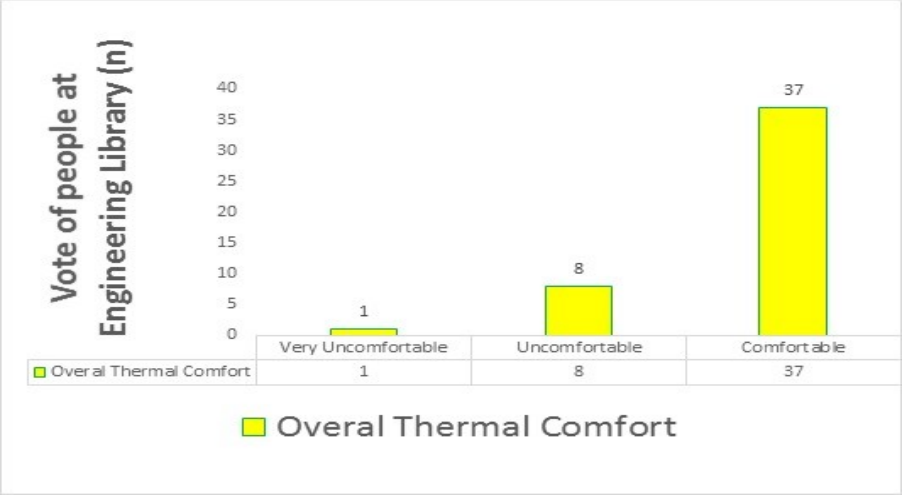

Fig. 13. Overall thermal comfort in the engineering library

3.3 Calculating PMV and PPD

Figure 14 and Figure 15 represent the calculated Predicted Mean Vote (PMV) versus Percentage of Predicted Dissatisfied (PPD) for 4 days study and the Mean of PMV and PPD respectively.

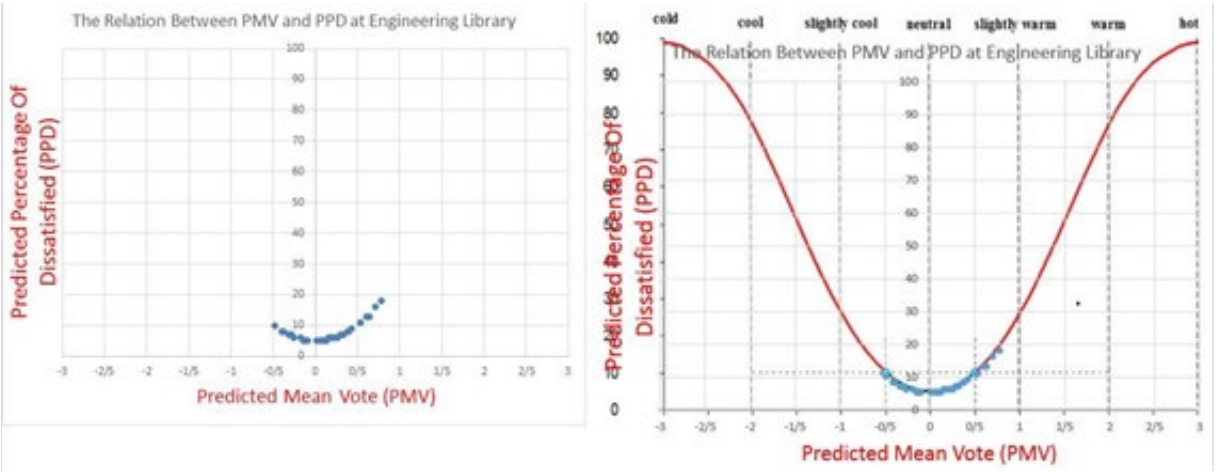

Fig. 14. Relationship between PMV and PPD for 4 Days

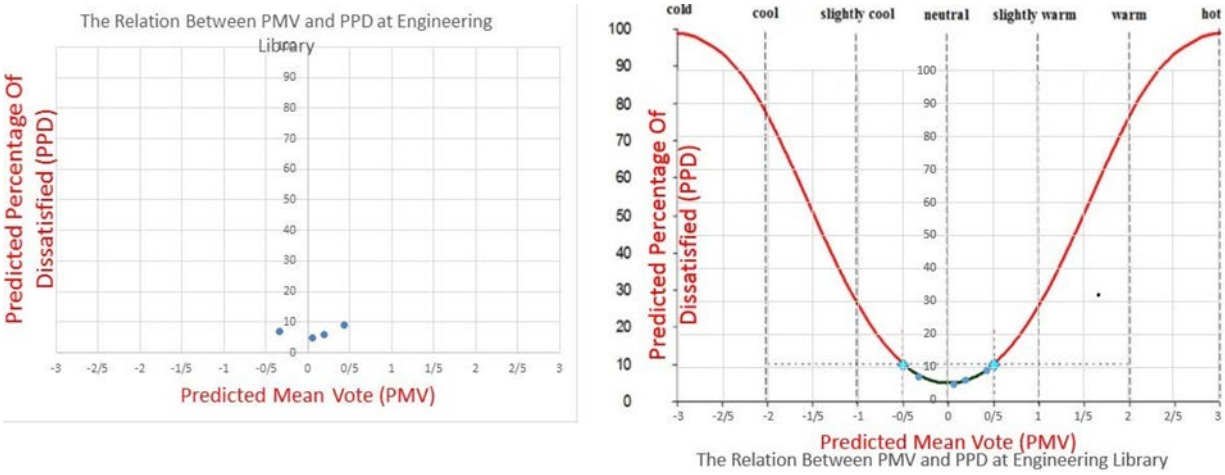

Fig. 15. Relationship between Mean of PMV and PPD

4. Conclusions

The study containing evaluation of thermal comfort acceptability in Engineering library of Universiti Putra Malaysia and determine thermal comfort and selected IAQ index of carbon dioxide and carbon monoxide on different days in October and November 2017. Based on ASHRAE Standard and ISO 7730, the result shows that the mean PMV level is 0.5 and the result of mean PPD is less than 11%, which means the most of occupants, 89%, feel comfort and thermal comfort in engineering library is acceptable for occupants. Also, when we go to detail parameter of thermal comfort day by day and time by time that the PMV level is +0.6 which means the occupation feel comfort and the result of PPD is around 11% of responders therefore the occupants voted discomfort is very less in engineering library and air condition system work properly. As a recommend, the use of green belt and plant inside the library, and considering some open windows can be reasonable to reduce the carbon dioxide level in the Engineering library. Another suggestion is considering an air curtain above automatic entrance door to avoid entering outside air into the library. Installing thermostat also can be useful to adjust the setting of air-conditioning temperature.

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