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Physical Measurement and Subjective Survey for Thermal Comfort Assessment in the Laboratories of Faculty Civil Engineering and Built Environment

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Abstract: Laboratory is the room for student practice the skill and handle the material and apparatus testing. Activities in laboratory require a certain level of metabolic rate and suitable apparel and a good level of indoor thermal condition should carefully to prevent thermal dissatisfaction. This research aims to investigate the thermal comfort level and indoor air conditioned of laboratory spaces in Faculty of Civil Engineering and Built Environment (FKAAB) building, University Tun Hussein Onn Malaysia. A field measurement was conducted to measure the indoor thermal condition of laboratories. Physical measurement and subjective survey had been conducted at three laboratories in FKAAB. The parameters that measured for the physical evaluations included air temperature, relative humidity, globe temperature and wind speed while subjective survey parameter used to evaluate the thermal sensation and thermal preference of the occupants. From the results, the activities during laboratory class for all laboratories can be conclude as discomfort for the occupants inside the spaces. For the current temperature, adjusting of air conditioner to a suitable temperature for all activities is needed to ensure the comfort condition for all selected laboratories.

Keywords: Laboratory, PMV, TSV, PPD

1. Introduction

Energy consumption is increasing over the years due to growing demand. The upward trend in building energy consumption will increase in coming years due to the expansion of building which are corresponding to energy demand [1]. High energy consumption will lead to environmental problems such as the heat island effect and poor outdoor air condition due to industries surrounding. Heating, ventilation and air-conditioning system (HVAC) is one of the contributors to the increase in energy in a building. Nonetheless, the thermal comfort of university tertiary students during the experimental study in engineering laboratories is barely studied. In a certain condition, another disadvantage such as

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bad indoor thermal condition makes the learning activities not conducive and discomfort. It was reported that in some cases the thermal condition of the laboratories has rarely been taken into consideration which causes the condition of too cold and too hot until which resulted in learning activities disturbed [2]. A body being too cold or hot as a whole or a particular part of the body being cooled or heated, i.e. local discomfort, may cause a certain level of dissatisfaction. The uncontrolled usage of air conditioners also leads to high-energy consumption due to less awareness of occupants. the unproper setting for the temperature will cause discomfort and make the high energy cost. Especially the building more than 10 years will need to reassess the setup and condition of the structure. This happen due to lack of inspection report on academic laboratory building[3].

The aim of this research is finding the level of thermal comfort and indoor air conditions of laboratory classes in the Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia. The selected laboratories were installed with the centralize air-condition system. In order to achieve this aim of the objectives. First objective is to investigate the indoor thermal condition of the laboratories during unoccupied and occupied. Second objective is to assess the thermal comfort condition in laboratories building by adaptive comfort equation, Predictive Mean Value method (PMV) and subjective survey. The field measurement is conducted 7-hours but mainly focus during office hour from 9.00 am to 4.00 pm.

2. Literature Review

Thermal comfort is a subjective state of mind that reflects contentment with one's thermal surroundings. The human body is a thermodynamic system that exchanges heat with its physical environment. [3]. Thermal comfort is the occupant feel when our bodies are functioning normally, with a core temperature of roughly 37°C and a skin temperature of 32-33°C [4]. Air conditioning's significant energy usage is partly attributable to the need for thermal comfort inside the building.

2.1 Thermal Comfort Parameter

Thermal comfort is difficult to quantify due to its subjective nature. It has long been recognised that a person's thermal comfort is not just a consequence of air temperature, but also of five other less evident characteristics; relative air velocity, mean radiant temperature, relative humidity, clothing thermal resistance and activity level.

2.1.1 Air Temperature

The average temperature of the air around the occupant with regard to place and time is referred to as the air temperature. According to ASHRAE 55 standard (2010), The recognize various takes into consideration the ankle, waist, and head levels, which change depending on whether the individual is sitting or standing.

2.1.2 Mean Radiant Temperature

The heat released by a heated object is known as thermal radiation. If there are heat sources in the surroundings, radiant heat may exist. The radiant temperature is proportional to the quantity of radiant heat conveyed from a surface and is determined by the material's capacity to absorb or emit heat, also known as its emissivity [5].

$$T_{mrt} = \left[(T_g + 273)^4 + \frac{1.1 \times 10^8 V^{0.6}}{\varepsilon D} \times (T_g - T_a) \right]^{0.25} - 273 \qquad \textit{Eq.1}$$

Where,
Tg = Temperature of the globe temperature
Ta = Air temperature
D = Diameter of globe temperature

2.1.3 Relative Humidity

Relative humidity is the ratio of water vapour in the air to water vapour that the air wants to maintain at the proper temperature and pressure (RH). Extremely dry circumstances (RH 20-30%) are also unsightly owing to their influence on mucosal membranes. However, new standards (such adaptive models) enable lower and higher humidity levels, depending on other elements involved in thermal comfort [6]. Relative humidity may be greater than 70% in non-air-conditioned workplaces or if weather conditions outside may impact the inside thermal environment.

2.1.4 Air Speed

The rate of air movement at a place, without regard to direction, is defined as air velocity (V). It is the average speed of the air to which the body is exposed in relation to distance and time, according to ASHRAE Standard 55 (2010).

2.1.5 Clothes

The amount of thermal insulation worn by an individual impacts heat loss and hence thermal comfort. Insulating layers of clothing help keep people warm or contribute to overheating. Subjects were assigned to one of five common ensembles (Table 1) based on their best fit. Table 1 includes clo values for underwear and footwear.

Table 1: Clothing thermal insulation [3]

Ta (°C)	No.	Clothing ensembles	I_{cl} (clo)
28	28°C- 0	Short-sleeve T-shirt; short pants; sandals	0.30
	28°C-U$^+$	**Long**-sleeve T-shirt; short pants; sandals	0.33
	28°C-L$^+$	Short-sleeve T-shirt; **long** pants; sandals	0.42
22	22°C- 0	Long-sleeve T-shirt; long pants; light jacket; socks; shoes;	0.77
	22°C-U$^+$	**Plus sweater**	1.00
	22°C-L$^+$	**Plus long woolen underwear**	1.00
16	16°C- 0	Underwear with long sleeves and legs, trousers, sweater, light jacket, socks, shoes	1.11
	16°C-U$^+$	**Plus another sweater**	1.35
	16°C-L$^+$	**Plus long woolen underwear**	1.35
10	10°C- 0	Underwear with long sleeves and legs, trousers, sweater, down jacket, socks, shoes	1.32
	10°C-U$^+$	**Plus another sweater**	1.56
	10°C-L$^+$	**Plus long woolen underwear**	1.56

Note: Series U$^+$ added additional clothes to the upper body; Series L$^+$ added additional clothes to the lower body.

2.1.6 Activity

Metabolic is used to calculate activity level. The most exact way to estimate met is through laboratory studies that measure heat or oxygen production by people doing certain tasks [7].The metabolic rate of an individual varies with exercise and environment. The ASHRAE 55-2010 Standard defines metabolic rate as the rate at which chemical energy is transformed into heat and mechanical work inside an organism.

3. Methodology

Lab 1, Lab 2, and Lab 3 are the three experimental laboratories. They are on the ground floors of the FKAAB building adjacent the FPTV building. The room size varies depending on the lab function. The rooms vary in size, apertures, and amenities such as one air conditioner inlet, ventilation, and lighting. In the present study, two type of method which is physical measurement and subjective survey were adopted.

3.1 Physical Measurement

This case study's field measurements include air, relative humidity, temperature, and wind speed. This study used proper equipment to avoid measurement mistakes. Sensor equipment was carefully placed near to the window, center, and entry for all criteria.

- Type of sensor used
  There are few sensors equipment that used in this study to get parameters required include relative humidity, air temperature, globe temperature, wind speed, HOBO Logger and Thermo recorder TR-72U to get air temperature.
- Location of equipment
  The measurements were made in known or probable habitation areas. They can be workstations or sitting areas, depending on the space. We measured occupant locations in occupied rooms. The sensors are 110cm from the floor in the laboratory's centre.
- Duration of Measurement
  Each case takes 4 days to field measure. The readings were obtained for 7 days. Since the laboratory facility operates during office hours, the important time for outdoor measurements is 9.00 am to 4:00 pm.

3.2 Data Processing

All of the data and parameters gathered during the case study experiment will be utilized to calculate the discomfort hour during office hours. The data was graphed as a regular temperature vs time graph. The graph was then transformed into Operative temperature versus time for each data.

Operative temperature [8]

$$t_o = \frac{(t_a + t_{mr})}{2} \quad Eq.2$$

Where,

t_a = Air temperature

t_{mr} = Mean radiant temperature

Or

$$t_o = \frac{(t_{mr} + (t_a \times \sqrt{10v})}{1 + \sqrt{10v}} \quad Eq.3$$

Where,

v = Air velocity

t_a = Air temperature

t_{mr} = Mean radiant temperature

After that, adaptive thermal equation was used to identify the discomfort hour of non-laboratory class. Adaptive thermal equation formula is shown as:
Adaptive comfort equation:

$$T_{neutop} = 0.57T_{autdm} + 13.8$$
$$T_{upper} = T_{neutop} - 0.7 \; for \; 80\%$$

PMV is group of individuals voting on thermal sensation. There will be disparities in picks among a group since everyone has their own point of view. As a consequence, knowing the proportion of people uncomfortable with the surroundings is vital (PPD).

$$PPD = 100 - 95 \times exp^{(-0.03353PMV^4 - 0.2179PMV^2)} \quad Eq.4$$

According to the equation above, around 5% of individuals may be dissatisfied with the surroundings even when the situation is thermal neutrality (PMV = 0). Contrarily, the difference between actual and required heat flow for maximal comfort during an activity may be determined using the following equation:

$$PMV = [0.303.\exp(-0.036M) + 0.028]L \quad Eq.5$$

Where,

M = metabolic rate

L = thermal load or defined as the difference between the internal heat production and the heat loss to the actual environment for a person.

3.3 Subjective Measurement

Questionnaire covering the indoor thermal response at the same period of the day, in morning until evening from 9:00 am until 4:00 pm specifically, using ASHRAE thermal comfort scale of +3 for (hot) to -3 for (cold) were distributed at selected laboratories.

- Thermal Comfort Survey
  The questionnaire covered certain areas including the demographic (sex, age, date, and time).Next, the questionnaire about thermal environment point-in survey includes the location of the occupant, the scales of thermal sensation and thermal preference. The seven-point thermal preferences scales used, asked if respondent want to change their thermal environment [8]. This questionnaire also asked about the occupants' clothing insulation value and thermal perception. The four-point air movement vote and five-point thermal preference scales were also employed. based on Table 2 below:

Table 2: Thermal environment scale

Thermal sensation vote Scale		**Air movement vote Scale**		**Thermal Preference Scale**	
-3	Cold	1	No movement	-2	Much cooler
-2	Cool	2	Weak	-1	Slightly cooler
-1	Slightly cool	3	Moderate	0	No change
0	Neutral	4	Strong	1	Slightly warmer
1	Slightly warm			2	Much Warmer
2	Warm				
3	Hot				

The survey is about thermal comfort. The questionnaire will ask the occupant about the permissible laboratory temperature, overall thermal comfort sensation rating, thermal environment while voting and explain the latest laboratory situation.

4. Results and Discussion

The sensors recorded the air temperature, relative humidity, wind speed, and globe temperature. This chapter will explain the results data acquired for analysis. Also, the data were categorised into Lab 1, Lab 2, and Lab 3. The occupants of laboratories buildings have gathered subjective measurements to assess their contentment.

4.1 Physical Parameter findings

4.1.1 Analysis Indoor Thermal Condition

(a) Lab 1

The Figure 1 below represents the graph for the air temperature,AT against time. According to the graph, the maximum air temperature in outdoor labs is 36.8°C. Because it is hot and humid outdoors. The lowest recorded outdoor temperature is 23.8°C. The maximum air temperature in labs is 29°C. The sensor recorded the lowest temperature of 21.3°C in labs. It had no mechanical ventilation and no laboratory class, thus the highest temperature was recorded. When no laboratory class, the ambient temperature is 29-27°C. The laboratory class lowers the air temperature (AT1 & AT2).

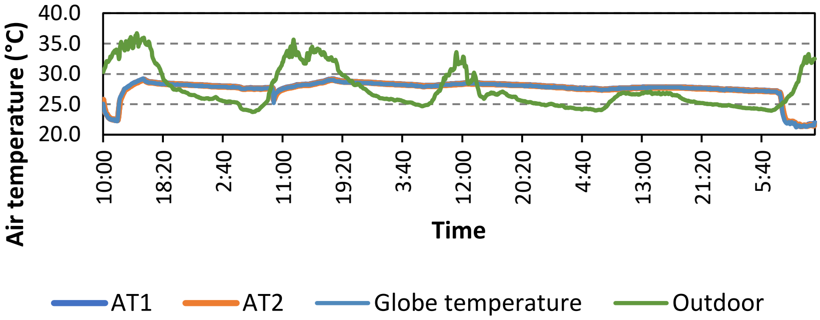

Figure 1: Air Temp against Time

Figure 2 compares the relative humidity versus time graphs for Lab 1 in both outdoor and indoor conditions. That was RH 1, RH 2, and Outdoor RH. The graph shows that the highest relative humidity in outdoor laboratories is 97.2%. Outdoor labs need a minimum relative humidity of 52.3%. Due to the hot sunny weather, the relative humidity decreases. So the humidity drops. Indoor labs have a maximum relative humidity of 87.6%. The average of both sensors' lowest relative humidity is 67.1%. Outdoor relative humidity was somewhat greater than inside relative humidity. Because building construction affects indoor and outdoor humidity during sunny days. The laboratory class lowers the relative humidity (RH1 & RH2).

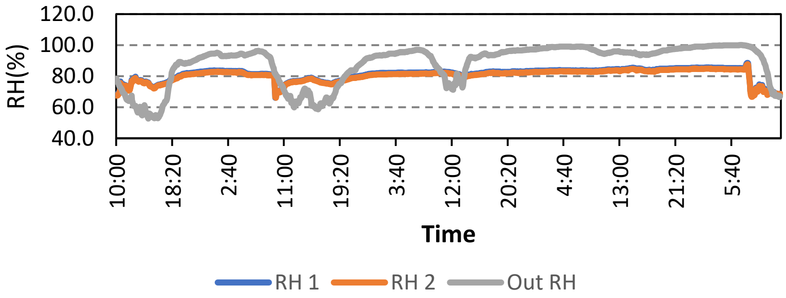

Figure 2: Air Temp against Time

Figure 3 shows the graph of wind speed versus time using the sensor in Lab 1. The maximum wind speed for interior labs is 0.38 m/s. Because no mechanical ventilation was turned on, the sensor's minimum and average windspeed remained at 0.2 m/s. The air speed rises due to the laboratory class and occupants.

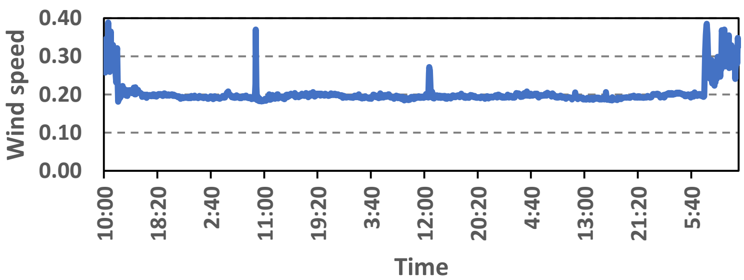

Figure 3: WS against Time

(b) Lab 2

Figure 4 below show that the graph of air temperature against time for Lab 2. According to the graph, the maximum air temperature in outdoor labs is 35°C. Because it is hot and humid outdoors. The lowest recorded outdoor temperature is 24.7°C. The maximum air temperature in labs is 27.1 °C. The average data showed the lowest temperature for labs was 20.1°C. It had no mechanical ventilation and no laboratory class, thus the highest temperature was recorded. When no laboratory class, the ambient temperature is 27°C to 25°C. The laboratory class lowers the air temperature (AT1 & AT2).

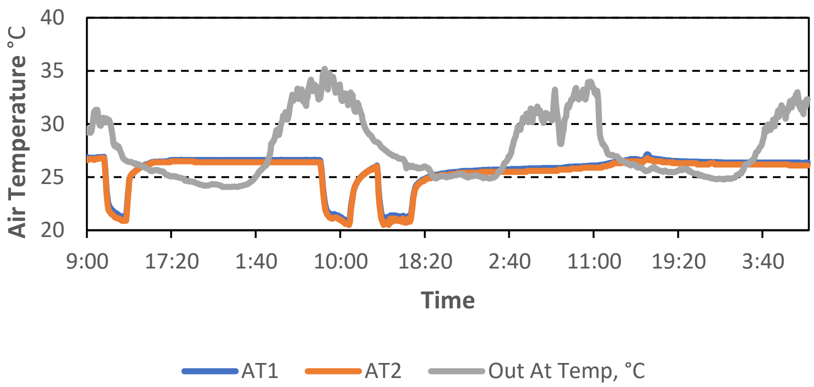

Figure 4: AT against Time

Figure 5 below show that the graph of relative humidity versus time for Lab 2. The graph shows the highest relative humidity of 97% in outdoor labs. Outdoor labs need a minimum relative humidity of 56%. Due to the hot sunny weather, the relative humidity increases at night and decreases throughout the day. So the humidity drops. The average maximum relative humidity measured by the sensor for indoor labs is 86 percent. The average of both sensors shows a minimum relative humidity of 65%. Outdoor relative humidity was somewhat greater than inside relative humidity. Because building construction affects indoor and outdoor humidity during sunny days. The laboratory class lowers the relative humidity (RH1 & RH2).

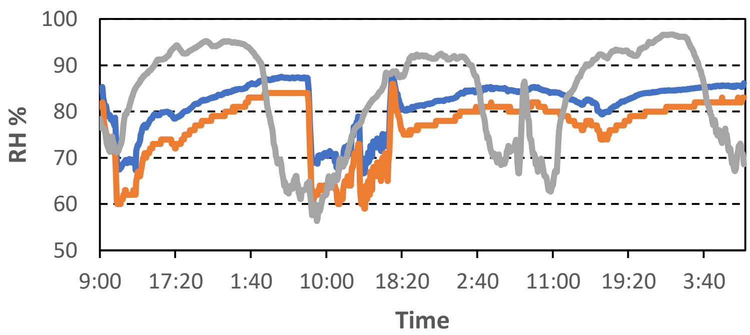

Figure 5: RH against Time

Figure 6 shows the graph of wind speed versus time using the sensor in the middle of Lab 2. The maximum wind speed for interior labs is 0.37 m/s. Due to no mechanical ventilation, the sensor registered a minimum and average windspeed of 0.2m/s. The sensor is also off during non-working hours, thus the air speed is 0m/s. The air speed rises due to the laboratory class and occupants.

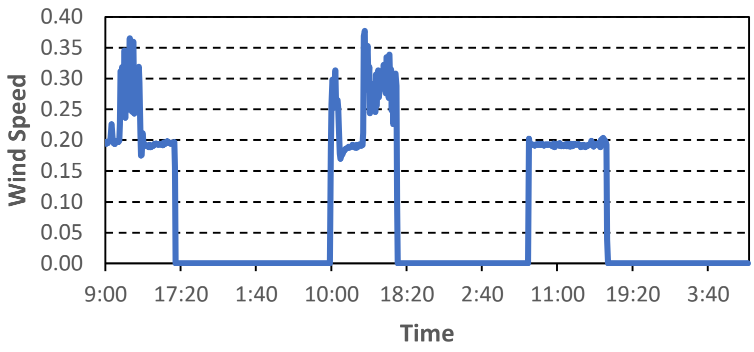

Figure 6: WS against Time

(c) Lab 3

Figure 7 below show that the graph of air temperature against time for Lab 3. According to the graph, the highest air temperature in outdoor labs is 35.6°C. The lowest recorded outdoor temperature is 24.1°C. The average maximum air temperature in labs is 27.2°C. The average results showed the lowest temperature for laboratory conditions was 20.2°C. It had no mechanical ventilation and no laboratory class, thus the highest temperature was recorded. When no laboratory class, the ambient temperature is 27°C to 25°C. The laboratory class lowers the air temperature (AT1 & AT2).

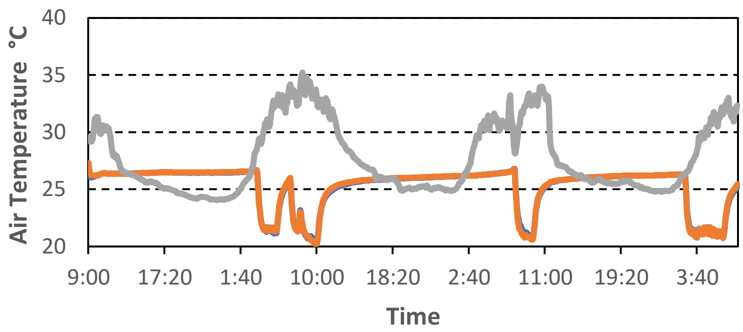

Figure 7: AT against Time

Figure 8 below show that the graph of relative humidity versus time for Lab 3. The graph shows the highest relative humidity of 96.8% in outdoor laboratories. Outdoor labs need a minimum relative humidity of 56%. The average maximum relative humidity measured by the sensor for indoor labs is 83%. The average of both sensors shows a minimum relative humidity of 67%. Outdoor relative humidity was somewhat greater than inside relative humidity. The laboratory class lowers the relative humidity (RH1 & RH2).

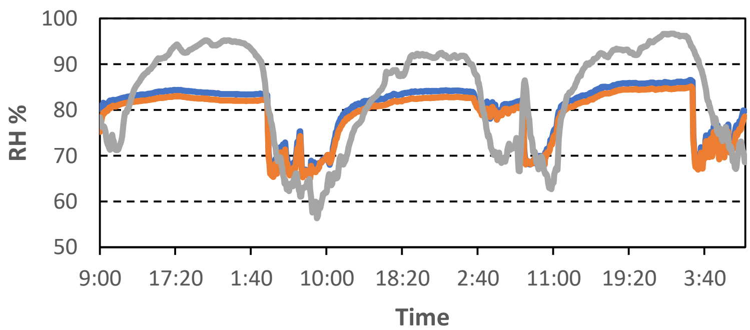

Figure 8: RH against Time

Figure 9 shows the graph of wind speed versus time using the sensor in Lab 3. The maximum wind speed for interior labs is 0.39 m/s. Due to no mechanical ventilation, the sensor registered a minimum and average windspeed of 0.2m/s. The air speed rises due to the laboratory class and occupants.

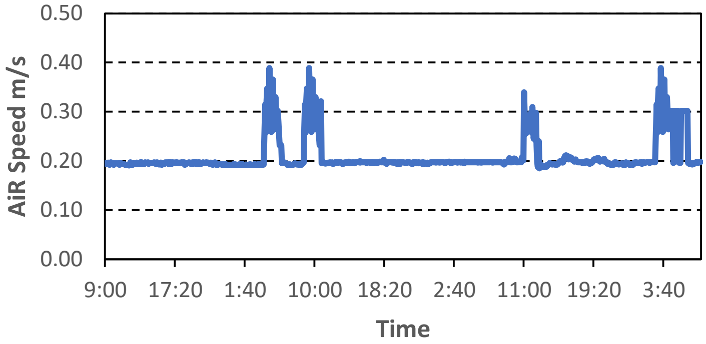

Figure 9: WS against Time

4.2 Analysis Thermal Comfort

- Operative Temperature and Adaptive Comfort Equation

Figure 10 shows the operating temperature vs. time graph of Lab 1. The adaptive comfort equation at 80% is 29.4°C. During the four-day analysis, the operating temperature of Lab 1 grew progressively. On the graph, no average operational temperature surpassed the adaptive comfort equation. So, the interior level is tolerated and may be improved by natural ventilation or with a fan. The adaptive comfort equation was used in non-ventilated conditions. Figure 11 shows the time-temperature curve of Lab 2. The adaptive comfort equation averages 28.9°C at 80%. During the four-day analysis, the operating temperature of Lab 2 grew steadily. On the graph, no average operational temperature surpassed the adaptive comfort equation. Figure 12 below show the graph of operative temperature against time of Lab 3. The average adaptive comfort equation at 80% is 28.9°C. Also, the operative temperature of Lab 3 during four days analysis increased gradually when the laboratory class are held.

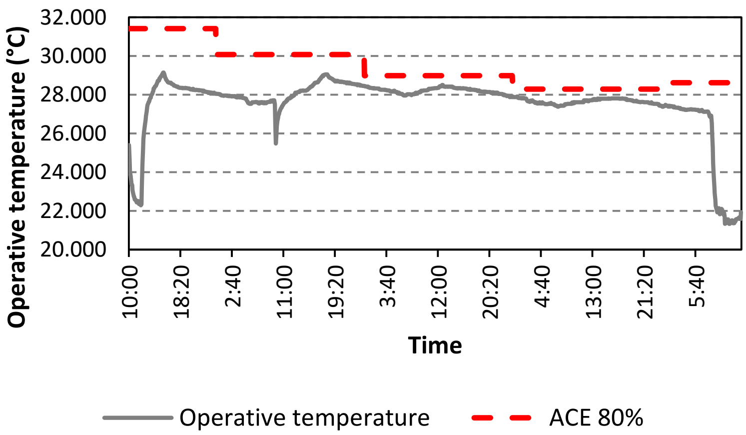

Figure 10: Operative temperature against Time Lab 1

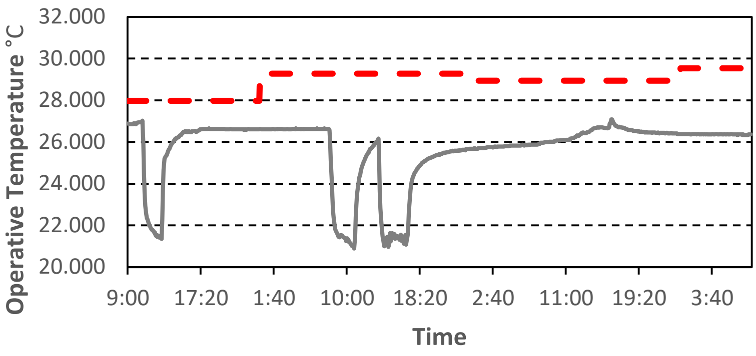

Figure 11: Operative temperature against Time for Lab 2

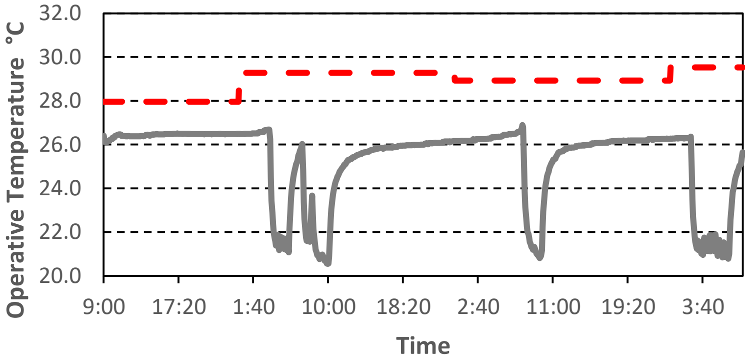

Figure 12: Operative temperature against Time Lab 3

- Predicted Mean Vote and Predicted Percentage Dissatisfied Analysis

The Figure 13, Figure 14 and Figure 15 shows the graph of Predicted Percentage Dissatisfied (PPD) against Predicted Mean Vote (PMV) against time for Lab 1, Lab 2 and Lab 3 respectively. The Figure 13 indicate the highest value of PMV is -1.8 and the lowest was -2. The graph illustrated that was "Slightly Cool" to "Cold" condition in term of thermal sensation. The highest value of PPD is 78% and the lowest was 12%. Figure 14 indicate the highest value of PMV is -1.4 and the lowest was -2.4. The graph illustrated that was "Slightly Cool", "Cool" to "Cold" condition in term of thermal sensation. The highest value of PPD is 82% and the lowest was 25%. Figure 4.15 indicate the highest value of PMV is -1 and the lowest was -2.3. the highest recorded value of PPD is 89% and the lowest was 24%. Also, same with sensation with Lab 2. The graph represents the overall PPD value more than 20% so this indicates non-preferable environment.

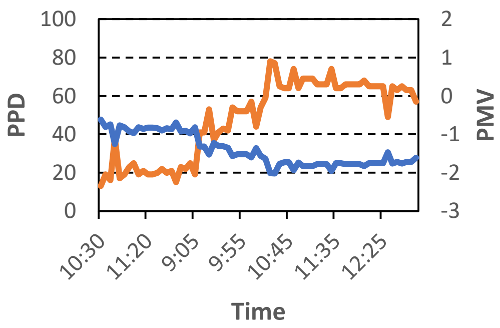

Figure 13: PMV against PPD Lab 1

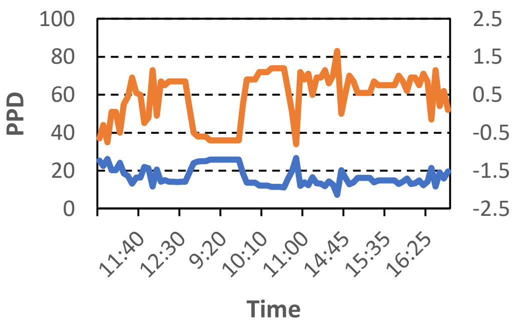

Figure 14: PMV against PPD for Lab 2

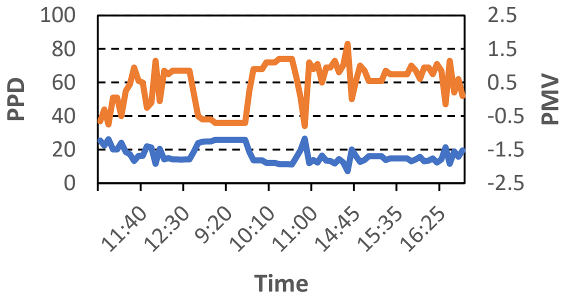

Figure 15: PMV against PPD for Lab 3

4.3 Subjective Measurement findings

The Figure 16 below show the graph TSV against Lab1, Lab 2and Lab3. The graph represents the overall occupant of thermal sensation vote in selected laboratories. TSV for the Lab 1 shows 20%, 50%, 30% and 10% are occupant have been voting “Cold (-3)”, “Cool (-2)”,” Slightly cool (-1) and “Neutral (0) sensation respectively. Meanwhile, TSV for the Lab 2 show occupant have been vote “Cold (-3)” sensation is 20%, “Slightly cool (-1)” sensation is 50%, “Neutral (0)” sensation is 30% and “Slightly warm (+1)” sensation is 10%. Also, TSV for the Lab 3 shows 20%, 60%, 10% and 10% are occupant have been voting “Cold (-3)”, “Cool (-2)”,” Slightly warm (+1)” and “Warm (+2)” sensation respectively. So, the average thermal sensation vote for Lab 1, Lab 2, and Lab 3 is “Cool (-2)”, “Slightly cool (-1)”, and “Cool (-2)” respectively. The overall occupant voted the sensation below cold condition during laboratory class.

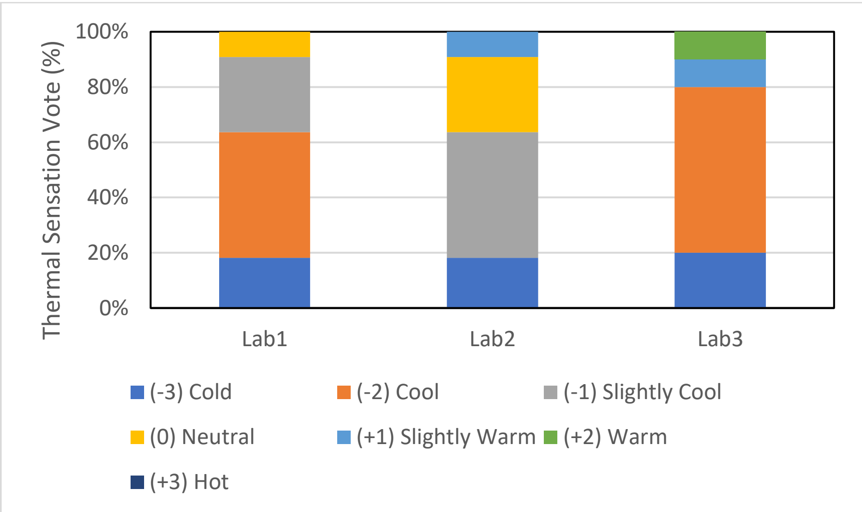

Figure 16: TSV against Lab 1, Lab 2, and Lab 3

5. Conclusion

The thermal condition during no laboratory class is warm condition based on the Adaptive Comfort Equation. The data have been recorded the temperature range between all laboratories which is between 29°C until 31°C. Therefore, the thermal condition during laboratory class is cold sensation. The data showed the temperature range between all laboratories is between 20°C until 22°C. Result of subjective survey by the Thermal Sensation Vote (TSV) shows a good agreement between calculated PMV value. Moreover, value where most of respondent state that the indoor laboratories condition was in “Cool (-2)” sensation. So, the activities during laboratory class for all laboratories can be conclude as discomfort for current temperature. By adjusting the current temperature to suitable temperature for all activities to ensure the comfort condition for all selected laboratories.

Acknowledgement

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References

[1] S. A. Damiati, "Field study on adaptive thermal comfort in office buildings in Malaysia, Indonesia, Singapore, and Japan during hot and humid season," *Building and Environment,* p. 208–223, 2016.

[2] M. Hussin, "Thermal comfort study of air-conditioned university," Int. J. Environmental Technology and Management, Penang, Malaysia, 2014.

[3] F. Nicol, "Adaptive thermal comfort standards in the hot–humid tropics.," *Energy and buildings,,* pp. 628-637., 2014.

[4] D. B. L. Clement, "Productivity and Indoor Enviroment," *Proc. Health Building Vol 1,* pp. 629-631, 2011.

[5] F. L. a. S. T. Holmer, "Mean radiant temperature and the shape of the standing man," Dept Earth Sciences, University of Gothenburg,, Sweden, 2018.

[6] P. K. Wolkoff, "The dictonomy of relative humidity om indoor air quality," pp. 850-857, 2007.

[7] G. Havenith, "A database of static clothing thermal insulation and vapor permeability values of non-Western ensembles for use in ASHRAE standard 55, ISO 7730, and ISO," 2015.

[8] Turner, "ASHRAE STANDARD Thermal Environmental Conditions for Human Occupancy," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., United States, 2010.