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Investigation of Thermal Comfort in UTHM Library

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Abstract: Educational system becomes agenda in order to produce a dynamic generation in this arena. As such, to reach the objective, the government has established different infrastructures and public buildings such as libraries. Thermal comfort has a crucial impact on the productivity and thermal satisfaction to indoor building's occupants. This research project presents a study of thermal comfort in Universiti Tun Hussein Onn Malaysia (UTHM) Library. The study aims to produce a mathematical model to predict the comfort air temperature range in UTHM Library. The methodology adopted for the study involves the physical measurement of environmental through TSI VelociCalc Plus air velocity meter and KIMO AMI 310 and personal variables through questionnaire survey. The environmental variables include air temperature (°C), radiant temperature (°C), air velocity (m/s) and relative humidity (%), while the personal variables are metabolic rate (met) and clothing insulation (clo). The data were collected in UTHM Library level two at morning and evening sessions for three days. There were total 60 responses across eight air-conditioned library level two open spaces with 20 responses per day. In general, the findings showed that the subjective response using the questionnaire survey had met the minimum vote of 80% satisfaction. Similarly, the PMV and PPD of -0.10 and 5% for morning session and -0.28 and 7% for evening session respectively were determined by the ASHRAE thermal comfort tool. By using linear regression equation, the relation between air temperature, PMV and TSV were obtained. The results showed that the TSV model was more sensitive than the PMV model but both models still can used for the prediction of comfort air temperature range.

Keywords: UTHM Library, Thermal Comfort, Comfort Temperature Range

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1. Introduction

Education plays an important role on economic growth and developing human behaviour. To create a diverse generation throughout this arena, the educational system becomes an objective. This could be accomplished by allowing the nation to enhance the standard of human beings' lifestyle. As such, to reach the objective, the government has established different infrastructures and public buildings such as libraries. The number of public library data in Malaysia was recorded in Dec 2016 at 1,440 units [1]. One of the library is from University Tun Hussein Onn Malaysia. UTHM is known because it has the largest library in South East Asia since May 2010. The first library in UTHM began operating on 1st October 1993. At that time that was only a two storey building that can accommodate 120 users. In year 2000, the library building was extended to withstand the increasing number of users. For now UTHM Library is a 5 storey building and has a floor area of 16000 square metres. It is so big that it could accommodate at least 3000 users.

A library seems to be a place where university students and learning programs, such as lecture rooms and auditoriums, provide a good study environment. A library also serves as a top management administrative office, a discussion area, and a conference room. Library provision would foster the culture of reading among the society. Therefore, to insure the facilities offered meet the expectations of library users, the government has to consider every dimension of its provision. A library should operate in good condition and fulfil the requirements for human comfort, and also a good atmosphere and thermal comfort. Thermal comfort is defined condition of mind which expresses satisfaction with the thermal environment as defined in American Society of Heating Refrigerating and Air Conditioning Engineers Standard 55 (ASHRAE Standard-55) [2]. ASHRAE also states that thermal comfort inside buildings is achieved when the indoor environmental conditions satisfy 80% of office occupants, owing to the fact that it is practically impossible to please all the occupants even some of the time [2]. Heating, ventilation, and air conditioning (HVAC) engineering design is important in achieving thermal comfort based on six basic factors that affect thermal comfort which are, air temperature, radiant temperature, air velocity, relative humidity, metabolic rate, and clothing.

1.1 Problem Statement

Today, individuals spend over than 90% of their time in buildings [3]. In Malaysia, the poor design of the building causes they often overheated at the daytime and too cool at the night. So, the people install HVAC system inside the building and set it at a very low temperature to cool them. One of the HVAC system's tasks would be to maintain comfort inside the building across the year. In formulating new buildings of strong environmental quality coupled with high quality indoor thermal comfort, architects and engineers have a really critical part to play with. Once people are uncomfortable with their thermal environment, their job satisfaction and their ability to perform efficiently will be affected. Throughout terms of productivity and satisfaction, thermal comfort really has a significant impact on occupants who stay in indoor buildings. Based on what we're wearing and what our surrounding conditions are like, we often continuously lose the heat. When the levels of heat gain and loss become unequal, we will feel uncomfortable.

In addition, electrical energy usage was produced by TNB in the UTHM Library. From the electrical bill of year 2016, the total electricity consumption in year 2016 is 3,914,664 kWh [4]. From these data, air conditioning is the major reason of the high electricity energy consumption. Based on research conducted by Z Noranai & ADF Azman [4], the breakdown of electricity consumption for air conditioning is 75% followed by electricity for lighting and other equipment is 25% [5]. Kwong et al determined that a decrease in energy consumption can be obtained when the predefined of the thermostat is set to 2.0 ◦C higher [6]. Zhang et al. improved the room air temperature and proposed that attention should be given to the air velocity in the room. By recognizing the thermal comfort of inhabitants, they gained a 7.8% reduction in energy consumption [7].

1.2 Objective

The objective of this study is to investigate the indoor thermal condition in UTHM Library during the different session of the day through physical and subjective measurement and also produce a mathematical model to predict the comfort air temperature range in UTHM Library.

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Case study building

Universiti Tun Hussein Onn Malaysia (UTHM) Library is the building discussed throughout this study. This library is based about 20 km from the city of Batu Pahat at 1 ° 51 '23.61N and 103 ° 4' 57.57 "E. This is a circular geometric shape building. It is also a multi-story building construct with five levels. For the ground floor, it consists of lecture room, lecture hall, computer room and a cafeteria. The actual library spaces were within level one to four and administration room is on the highest level. The overall building plan area is 8091 m^2 with a diameter of 101.5m. The courtyard area is 804 m^2 with inner diameter of 36 m and it is 13% of the total area.

2.2 Equipment

The device used for this case study were TSI VelociCalc Plus air velocity meter and KIMO AMI 310 that collected data for air temperature (°C), radiant temperature, air velocity (m/s) and relative humidity (%).

Figure 1: TSI VelociCalc Plus air velocity meter

Figure 2: KIMO AMI 310

2.3 Methodology

2.3.1 Data Collection

For the physical and subjective measurement, it was done in three days of observation (2^{nd} to 4^{th} of November 2020). For each day, the data collection was conducted for two time slots from 9.00 a.m. to 12.00 p.m. and 2.00 p.m. to 5.00 p.m. For physical measurement, it was taken ten minutes at each point with an interval of one minute for a total eight positions in UTHM Library level 2. The data taken were air temperature (°C), radiant temperature (°C), air velocity (m/s) and relative humidity (%). While for subjective measurement, the questionnaire survey was administered at the same time with the physical measurements in each library level two. The questionnaire survey collected the information of respondents included their clothing insulation (clo), metabolic rate (met) and thermal sensation vote.

2.3.2 Data Analysis

The thermal sensation vote by the occupants were collected and compared with the PMV. ASHRAE 7-point thermal sensation scale was used to determine the thermal condition of occupant. It states that thermally satisfied people are those who will vote slightly warm (+1), neutral (0) and slightly cool (-1).

For this case study, CBE thermal comfort tool was used to calculate the value of PMV and PPD based on the data collected. The data used for calculation of CBE thermal comfort tool were average data of air temperature, radiant temperature, air velocity and relative humidity during morning and evening session. The value of the clothing insulation and metabolic rate were referred from ASHRAE Standard [2]. The determination of this value was based on the subjective measurement of the occupant activity level and their clothing insulation in UTHM Library level two. The recommended range of PMV is located between range of -0.5 and +0.5, and PPD of less than 10%. However, in most buildings this 90% satisfied rating is rarely obtained, with maximum satisfaction around 80%.

2.3.3 Regression Analysis

The primary need of regression analysis is to understand the type of relationship between different variables [8]. The method used was a linear regression analysis. PMV and mean air temperature data for morning and evening session of UTHM library occupants can be used to estimate the relationship between them. The comfort air temperature for UTHM Library level two will be calculated based on the linear polynomial equation:

$$y = ax + d \qquad \text{Eq. 1}$$

This equation was used to identify the comfort air temperature range of UTHM Library level two with the acceptable range of PMV between $-0.5 < x < +0.5$ was inserted. The regression analysis of the air temperature against PMV methods for UTHM library level two was using Microsoft Excel software analysis

3. Results and discussions

3.1 Sample size

Table 1: Response rate of the respondents

Gender	No. of Respondents
Female	29 (48.3%)
Male	31 (51.7%)
Total	60 (100%)

Table 1 shows the response rate of the respondents. Table 1 describes the 60 responses polled from the respondents of eight open spaces across the library level two during the morning session and evening session. All respondents took the survey two times per day for the three days' duration, once in the morning session and once in the evening session. The sample included a total of 48.3% females and 51.7% males.

3.2 Clothing and metabolic rate

Figure 3 shows the average clothing value of respondents in UTHM Library level two. Respondents in library level two on day 1 had 0.62 clo. The clo value in day 2 was the highest with 0.65 clo and for the respondents in day 3 wore the least clothing with value (0.60 clo). The difference between clo value of respondents within these three day are not much different because there were not much respondents in UTHM Library during CMCO period and their attire were majority in Type D for men and women. For the Figure 4, it shows that the metabolic rate for all occupants were 1.2 met because the occupants were requested to stay at their own places for 30 minutes before they answered the questionnaire survey.

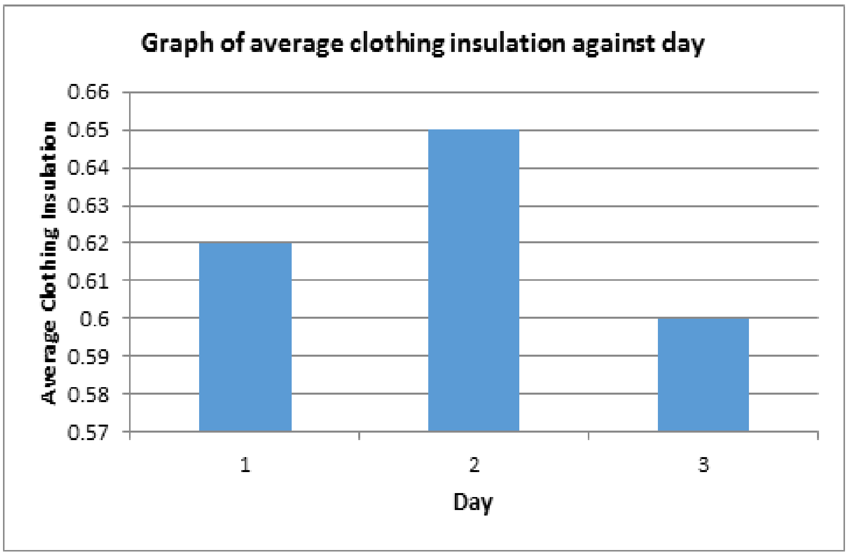

Figure 3: Graph of average clothing insulation against day

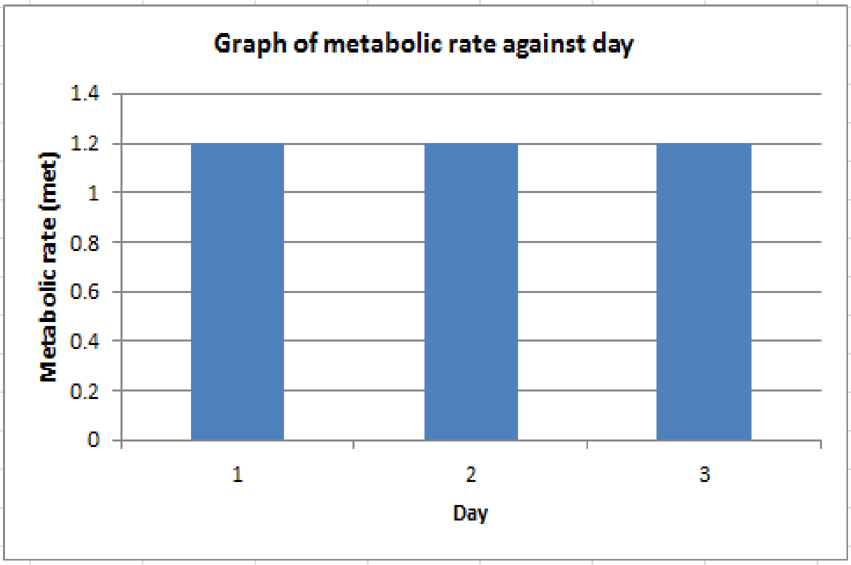

Figure 4: Graph of metabolic rate against day

3.3 Thermal sensation vote

Table 2: Thermal sensation voting range across the sessions for library level two

Day	Session	Thermal Sensation Vote		Thermal Sensation Vote ≥ 80%
		Observed Range	Vote (%) (-1, 0, +1)	
1	Morning	+1 to -3	90	YES
2	Morning	+1 to -2	90	YES
3	Morning	+1 to -2	85	YES
Average	Morning	+1 to -3	88.3	YES
1	Evening	+3 to -2	85	YES
2	Evening	+1 to -2	85	YES
3	Evening	+2 to -2	80	YES
Average	Evening	+3 to -2	83.3	YES

Table 2 shows the summary of thermal condition votes observed across library level two during the survey by sessions. The table shows the votes grouping and compare to ASHRAE Standard 55 requirement of greater than or equal to 80% for thermal comfort satisfaction [2]. Comparison of days across the sessions show that the morning session for these three days have the highest vote for thermal comfort (90%) and also greater than 80% for thermal comfort perception. Thus, it is concluded that morning and evening session in UTHM library level two around these three days are thermally comfortable for the respondents.

3.4 Mean air temperature

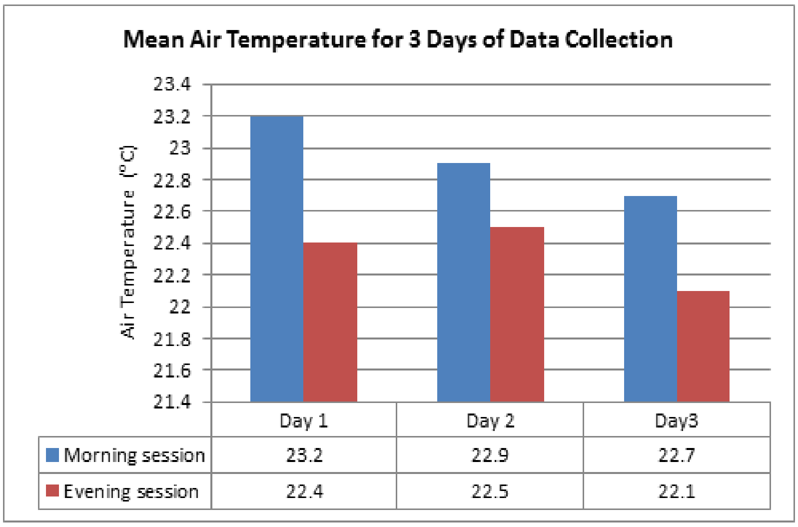

Figure 5: Mean air temperature for 3 days of data collection

Figure 5 shows the data distribution of air temperature for three days. The mean air temperatures collected in the library level two were 22.9°C in the morning session and 22.3°C in the evening session. The differences between the air temperatures collected in the library level 2 were not so significant. The recommended range in ASHRAE Standard-55 is between 20°C to 28°C [2].

3.5 Mean radiant temperature

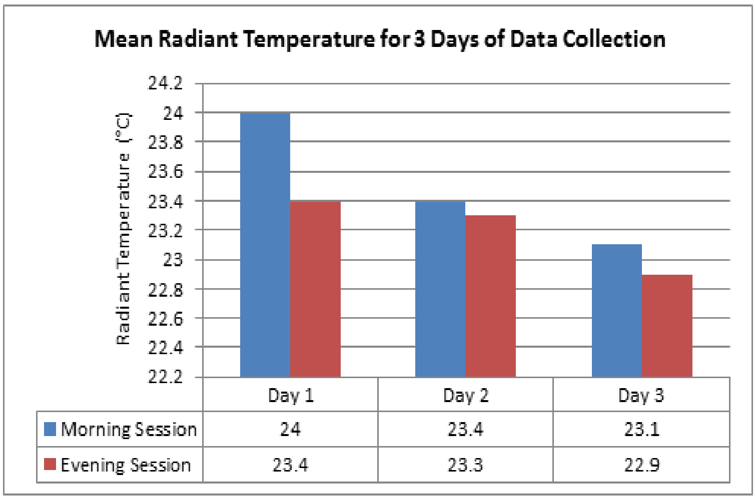

Figure 6: Mean radiant temperature for 3 days of data collection

The range of mean radian temperatures shown at Figure 6 were within 23.1°C to 24°C in the morning session and 22.9°C to 23.4°C in the evening session. There were no much differences for the radian temperatures because the direct sunlight was not so much in the morning. The data of mean air temperature and mean radiant temperature for evening session was lower than morning session because it was influenced by the weather. It was a cloudy day for evening session on the three day. On cloudy day, the sun's energy was not fully reached to the library through window due to the reflection off of some sun's rays. So, the temperatures on evening session will be cooler.

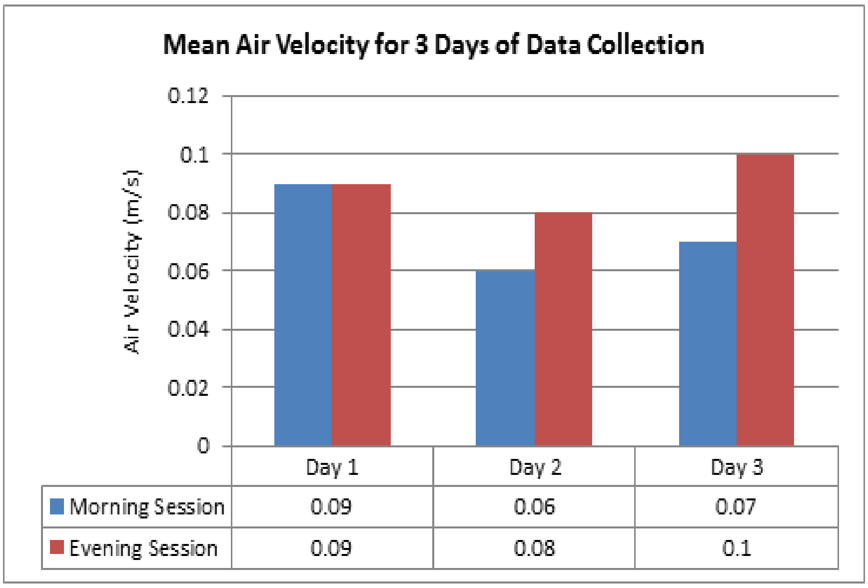

Figure 7: Mean air velocity for 3 days of data collection

Figure 7 shows the data distribution of mean air velocity over 3 days of data collection. The mean average air velocity of UTHM Library level two was 0.07 m/s for morning session and also 0.09 m/s for evening session. The upper limit value for average air velocity shall be ≤ 0.2 m/s [2]. In this study, the number of occupants and location of air inlets and outlets might influence the indoor air velocity.

3.7 Mean relative humidity

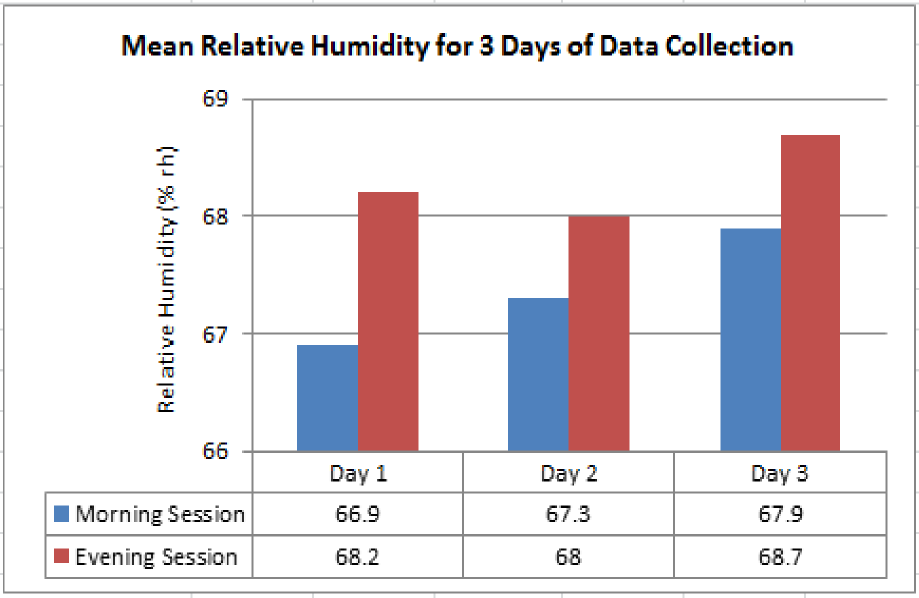

Figure 8: Mean relative humidity for 3 days of data collection

Mean relative humidity in the UTHM Library level two is shown in Figure 8. For the morning session, the relative humidity had the minimum value of 66.9% and maximum values of 67.9% while there was no much difference for the relative humidity in evening session with range within 68.0% to 68.7%. The mean relative humidity for the UTHM Library level two was 67.4% in the morning session and 68.3% for evening session. The allowable range of relative humidity by the ASHRAE Standard 55 [2] is ≤ 80%. For DOSH [9] and Malaysia Standard [10], the recommended range of relative humidity is between 40% - 70%. The highest relative humidity value was 68.3% which within the recommended range. It showed that air temperature was inversely proportional to relative humidity. As the air temperature decreases, the relative humidity increases.

3.8 PMV and PPD results

Table 3: PMV and PPD result for the three days of data collection

Day	Session	PMV	PPD (%)
1	Morning	-0.05	5
2	Morning	-0.06	5
3	Morning	-0.22	6
Average		-0.10	5
1	Evening	-0.24	6
2	Evening	-0.14	5
3	Evening	-0.42	9
Average		-0.28	7

Table 3 presents a summary of PMV and PPD result for the three days of data collection by using CBE thermal comfort tool. In the evening session with a range of 22.1°C to 22.5°C, the occupants can feel the coldness increases compared to morning session. The PMV and PPD value in the evening session were higher if compared to morning session. It showed that the occupants will consider there was a little bit thermally uncomfortable in the evening session although these values were still within the recommended range which -0.5 to +0.5 for PMV and 10% for PPD. Occupants prefer the temperature range of 22.7°C to 23.2°C in the morning session, considering a threshold greater than 80% for an acceptable thermal environment.

3.9 Regression analysis

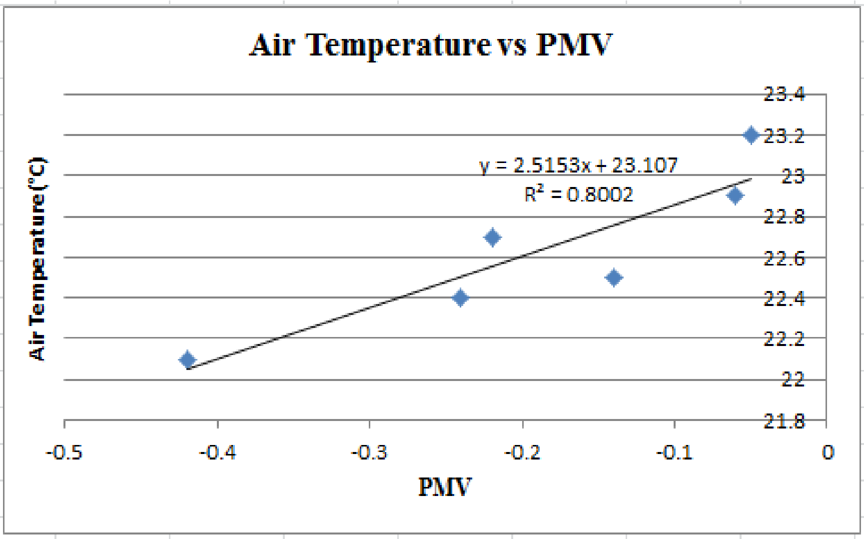

Figure 9: Linear relationship between air temperature and PMV

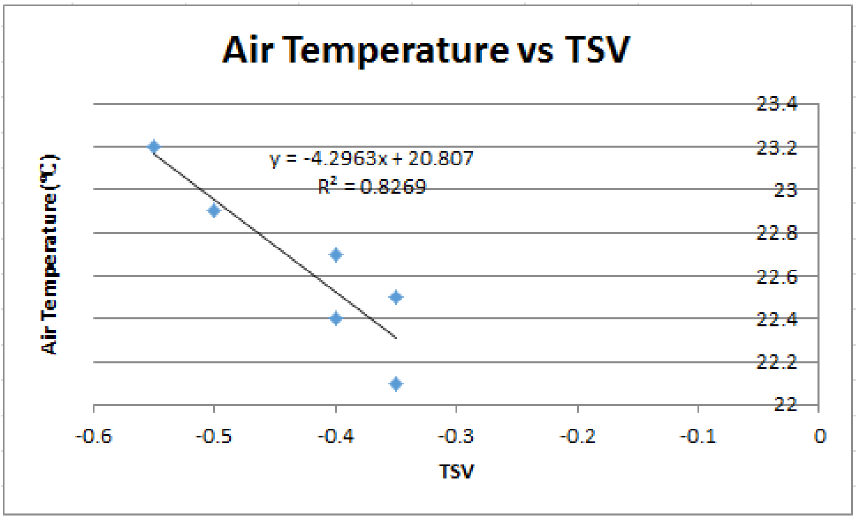

Figure 10: Linear relationship between air temperature and TSV

Figure 9 and Figure 10 show the linear relationship between air temperature, PMV and TSV for the result of physical and subjective measurement after the data collection process has conducted. This result was based on the PMV from thermal comfort tool and TSV for 60 samples under different temperature. The highest temperature measured was 23.2°C while the lowest temperature was 22.1°C. In terms of PMV, the highest and lowest PMV measured were -0.05 and -0.42 respectively. For TSV, the highest and lowest values were -0.35 and -0.55.

The most suitable relation used was linear regression equation which the equation of the relation for PMV was y = 2.5153x + 23.107. The comfort air temperature was 23.1°C and with the range of 21.8°C to 24.4°C. Figure 9 also show a good correlation with R^2=0.8002 and it showed its accuracy which is 80.02% accurate when this relation had implemented during the real time analysis. The comfort air temperature and its range were within the recommended range for ASHRAE Standard 55 [2] which is 20°C to 28°C. Based on Figure 10, the equation of the relation for TSV was y = -4.2963x + 20.807 with R^2 = 0.8269. The comfort air temperature was 20.8°C with a range of 19°C to 23°C. Interestingly, Figure 4.6and 4.7 shows oppose slope. In Figure 4.7, the higher the temperature, thee TSV become more smaller suggesting the occupant felling more colder when the temperature increase. This scenario happens due to the same occupant stay in the library from morning until evening and felt colder in the evening although the air temperature is increased. This shows some new insight on adjusting the temperature setting to slightly higher temperature probably would not cause any significant discomfort if most of the occupants stay in long period of time inside the library.

4. Conclusion

In conclusion, the study of thermal comfort in UTHM Library level two was carried out in this study. Physical measurement was conducted to collect the reading of air temperature, radiant temperature, air velocity and humidity at the model of study according to the measuring points stated. The thermal sensation vote for morning session and evening session in UTHM Library level two had met the requirements of the ASHRAE Standard 55 as identified to meet the ≥ 80% acceptability by the respondents with 88.3% and 83.3%. The results showed the relationship between air temperature and PMV after the data collection process has conducted. By using linear regression equation, the equation of the relation obtained was y = 2.5153x + 23.107 with R^2 = 0.8002. The neutral air temperature was 23.1°C with a range of 21.8°C to 24.4°C. While for the relationship between air temperature and TSV, the equation of the relation obtained was y = -4.2963x + 20.807 with R^2 = 0.8269. The comfort air temperature was 20.8°C with a range of 19°C to 23°C. The results showed that the TSV model was more sensitive than the PMV model but both models still can used for the prediction of comfort air temperature range.

There are several recommendations that can be proposed for the next study. They can consider thermal condition for the whole UTHM Library including all levels of library. The larger sample size for questionnaire survey should be considered in the further study to get the more accurate thermal sensation vote. Researchers may collect the physical measurement with a longer period which more than 10 minutes. Lastly, the simulation software should be used to evaluate the comfort temperature range in the next study.

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References

[1] Department of Statistics. (2007). Malaysia Education Statistics: Number of Libraries. Retrieved from https://www.ceicdata.com/en/malaysia/education-statistics-number-of-libraries

[2] ASHRAE (2017), ASHRAE Standard 55-2017: Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

[3] Frontczak, M. & Wargocki, P. (2011) Literature Survey on How Different Factors Influence Human Comfort in Indoor Environments. Building and Environment, 46, 922-937.

[4] Z Noranai & ADF Azman. (2017). Potential reduction of energy consumption in public university library. Retrived from https://iopscience.iop.org/article/10.1088/1757-899X/243/1/012023/pdf

[5] Noranai, Z., Mohamad, M. H. H., bin Salleh, H., & Yusof, M. Z. M. (2014). Energy Saving Measures for University Public Library: A Case Study of UTHM Library. Applied Mechanics and Materials, 660, 1072–1075.

[6] Kwong, Q.J.; Adam, N.M.; Sahari, B.B. (2014). Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review. Energy Build. 68, 547–557.

[7] S. Zhang, Y. Cheng, Z. Fang, C. Huan, and Z. Lin. (2017). "Optimization of room air temperature in stratum-ventilated rooms for both thermal comfort and energy saving," Applied Energy, vol. 204, pp. 420–431

[8] McCullough, E. A., Eckels, S., & Harms, C. (2009). Determining temperature ratings for children's cold weather clothing. *Applied Ergonomics*, *40*(5), 870–877.

[9] Department of Occupational Safety and Health (2010). Industrial Code of Practice on Indoor Air Quality. Ministry of Human Resource, Malaysia 2010.

[10] MS1525, M. S. (2007). Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Building (First Revision), Department of Standard Malaysia. In *ICS* (Vol. 91, No. 040, p. 01).