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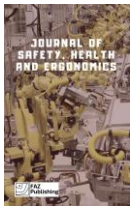

Thermal Comfort Study in Naturally Ventilated School Classroom in Parit Raja, Batu Pahat

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Abstract: Thermal acceptability among students in classroom is vital for the students' performance and well-being. The purpose of this study is to assess thermal comfort among school students based on ASHRAE Standard 55-2017. The study of thermal comfort was conducted at Sekolah Kebangsaan Jelutong, Parit Raja involving 56 primary students aged 10 years old in upper-level and ground-level classrooms. Subjective and physical measurement were conducted on both classes. Air velocity, relative humidity, air temperature, mean radiant temperature, and prevailing mean outdoor temperature were measured during physical measurement. Metabolic rate and clothing insulation value were estimated from observation done. Students were given a questionnaire to fill in for identifying their thermal sensation and thermal acceptability during subjective measurement. The physical measurement for upper-level classroom showed less than 80% of acceptability whereas from subjective measurement, the result shows 87% of acceptability. For ground-level classroom, the physical measurement showed 80% of acceptability of thermally condition in the classroom. However, from the subjective measurement, the results show slightly higher of thermally acceptability at 84%. Female students have higher thermal sensation vote's value because of their clothing insulation value is higher than male students. In conclusion, by comparing both of the classroom, upper-level classroom have higher thermal acceptability than ground-level classroom with the difference of 3% in value.

Keywords: Thermal comfort, thermal sensation, classroom, naturally ventilated

1. Introduction

The thermally comfortable environment in a room is essential to us as it can affect our daily activities. Thermal comfort is defined as 'that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation' by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [1]. Thermal comfort commonly related to a range of comfort temperatures in a building or a room specifically. According to the PMV model (Predicted Mean Vote) of Fanger which is the most common model used for evaluating thermal comfort within the built environment, the optimum condition defined as a thermal neutral condition. It is a condition wherein a person does not prefer either a colder or warmer environment condition ($-0.5 < PMV < 0.5$) [2]. An indoor environment that is too cold or too hot may affect the productivity and performance of a person. By evaluating their thermal comfort, the range of comfort temperature can be obtained. From that data, a thermally comfortable environment can be provided for them.

The method for evaluation of the thermal comfort can be referred to the ASHRAE Standard 55-2017. The purpose of this standard is to specify the combinations of indoor thermal environmental conditions acceptable to a majority of the occupants within the space[1]. While "acceptability" is never precisely defined by the standard, it is commonly agreed within the thermal comfort research community that "acceptable" is synonymous with thermal sensations of "slightly warm", "neutral", and "slightly cool" [3]. There are six factors that should be addressed in defining the conditions which are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. Metabolic rate and clothing insulation are associated with the occupants in the room while air temperature, radiant temperature, air speed, and humidity are conditions of the thermal environment. All of these factors can be possibly vary with time. In Malaysia, the majority of the classrooms in the schools are naturally ventilated with ceiling fans. The naturally ventilated classroom also can be classified as occupant-controlled naturally conditioned spaces.

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2. Literature

D. Teli et al. (2018) stated that current thermal comfort models are based on studies with the adult subjects whereas there is no assurance however that these models apply to children. A thermal comfort survey and field measurement being conducted among primary school students in Southampton, Hampshire, United Kingdom (UK). The obtained result from the study shows the difference between the pupil surveys and Smart Controls and Thermal comfort for United Kingdom (SCATs-UK) database of comfort temperature is 3.5 ℃ [8]. This study also suggests that the difference may indicate a potentially stronger influence of the outdoor climate on the surveyed primary school students than adults [8]. H. Yun et al. (2014) investigated the thermal preference among kindergarten children in Seoul, Korea. From the investigation, this study concluded that girls were more sensitive to heat than boys [9]. This study also concluded that children perceived comfort at a temperature of about 3 ℃ lower than that for adults [9].

Comfort temperature closely related to the climate of a country. Different people from different countries perceived comfort temperature distinctively. Malaysia's climate is categorized as equatorial being located near the equator [10] and the climate for Malaysia also can be considered as tropical. Malaysia does not have four seasons which are spring, summer, autumn, and winter because it located at the line of Khatulistiwa. There are always hot and humid throughout the year in Malaysia. According to the Malaysian Meteorological Department (2019), the differences in daily temperature range is from 5 ℃ until 10 ℃ for every station near the beach. For every station in the rural areas, the differences in daily temperature range are from 8 ℃ until 10 ℃ [11]. Malaysian Meteorological Department (2019) also stated that the monthly average temperature is the highest during the month of April and May whereas the lowest monthly average temperature is during December and January.

In the last few years, several studies on thermal comfort in naturally ventilation classrooms have been conducted by many researchers over the world. Table 1 shows several studies that have been performed on thermal comfort in the naturally ventilated classroom or lecture room (from primary school to university) of tropical and sub-tropical climate in the last 4 years.

Table 1: Data from previous study in thermal comfort

Researchers	*Country*	*Climate*	*Season*	*Age group*	*Sample size*	*Comfort temperature range (℃)*
M.K. Nematchoua et al, 2018 [12]	Madagascar	Tropical	Rainy and dry	University	625	24.6 - 28.4 (both seasons)
S.S.Y. Lau et al, 2018 [13]	Singapore	Tropical	Hot and humid	University	295	24.9 - 30.6
L.A. Lopez-Perez et al, 2018 [14]	Mexico	Tropical	Warm	University	181	26.1 (mean)
Shamila Haddad et al, 2016 [15]	Iran	Tropical	Summer	Primary school	811	25.7 - 26.0
S. Thapa et al, 2016 [16]	India	Sub-tropical	Summer and winter	University	356	21.2 - 29.7 (summer) 18.5 (winter)

3. Methodology

The flow process of the study that has been conducted to determine the comfort range temperature of school students in the naturally ventilated classroom is shown below in Figure 1. The design of this study is composed of three main elements which are questionnaire session, data collection method via physical measurement and data analysis by using an adaptive model of thermal comfort and CBE Thermal Comfort tool.

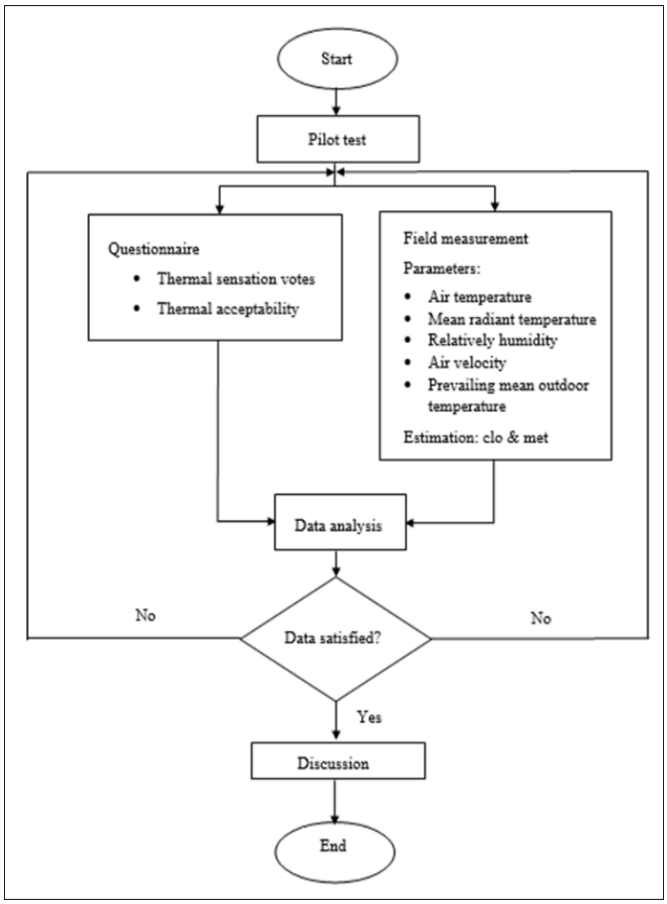

Figure 1: Flow process of the study

3.1 Subject and Location of Survey

Sekolah Kebangsaan Jelutong was chosen to be the location for this study to carry out the surveys. The surveys were conducted during the school working hours between 11 am until 12 pm. The age of the subjects is 10 years old. The surveys that were conducted comprises of questionnaire sessions and physical measurement. All of the subjects from the school filled out the questionnaire that was distributed at the same time where the physical measurement were carried out in the school classroom during the school working hours.

3.2 Questionnaire

The questionnaire used in this study acts as an instrument for collecting data obtained from the subjects' responses to their thermal comfort satisfaction. The questionnaire was distributed to the subjects after the measurement of parameters finished. The subjects have been briefly explained about the surveys before the questionnaire session started. As the subjects

are primary school students, the questionnaire was made easy for them to understand so that they did not have any difficulty in filling out the questionnaire. The questionnaire included the subjective perception of participants regarding the indoor thermal environment (temperature, relative humidity, and wind speed). Thermal sensation votes (TSVs) was cast on a seven-point thermal sensation scale; namely, (-3) cold, (-3) cool, (-1) slightly cool, and (0) neutral, (+1) slightly warm, (+2) warm, (+3) hot. The questionnaire also included question about their acceptability of the subjects regarding the classroom current temperature. After the questionnaire session is done, all of the data from the questionnaire were transferred into a spreadsheet to evaluate their responses. Data obtained from the questionnaire were used to obtain the mean TSV by using Equation (1) below.

$$Mean\ TSV = \frac{(n_1 \times x_1) + (n_2 \times x_2) + (n_n \times x_n)}{N} \quad (1)$$

Where n is number of students, x is value of the vote and N is total number of students. Then, the value were compared with ASHRAE Standard 55-2017 to determine the thermally comfort condition of a classroom.

3.3 Data Collection Method via Physical Instrument

Physical measurement is a method used by many previous researchers in collecting data in determining the comfort temperature in a naturally ventilated classroom. This method will collect certain parameters to determine the comfort temperature in the naturally ventilated classroom. The parameters that were measured for these surveys are air temperature, mean radiant temperature, relative humidity, air velocity, and prevailing mean outdoor temperature. The parameters at a representative sample of location were being measured continuously. The instruments being used in this study are VelociCalc meter and KIMO black globe thermometer. The devices are shown in Figure 2.

The instruments used have been calibrated prior to the measurement. The instrument recorded automatically every 1 minute based on ASHRAE 55-2013 on determining acceptable thermal conditions in occupant-controlled naturally ventilated conditioned spaces. The instruments used were placed minimum at one point in the classroom while the students carry out their activities. The measurement began 10 minutes after the start of the class for the subjects to fully settle and the temperature in the class to reach thermal equilibrium. The parameters were measured continuously for 30 minutes. The data of the parameters obtained from the field measurement can be used in the Centre for the Built Environment (CBE) Thermal Comfort tool to find the range of acceptable operative temperature.

(a) (b)

Figure 2: (a) Velocicacl meter; (b) Kimo black globe thermometer

4. Results and Discussion

The physical measurement was conducted on 18 November 2019 for upper-level classroom and 19 November 2019 for ground-level classroom. The measurement was conducted from 11 am until 12 pm for both classrooms. The metabolic rate of the students for both classrooms is 1.2 as the activities done by them were sitting and writing. The clothing insulation of the students for both classrooms is 0.62 for the male students and 0.94 for female students. Both of the metabolic rate and clothing insulation value met the requirement from ASHRAE Standard 55-2017[1] for naturally ventilated spaces.

4.1 Determination of Thermal Comfort using CBE Thermal Comfort Tool

Physical measurement is a method used by many previous researchers in collecting data in determining the comfort temperature in a naturally ventilated classroom. This method will collect certain parameters to determine the comfort temperature in the naturally ventilated classroom as shown in Table 2.

Table 2: Parameters to be used for CBE Thermal Comfort tool

Classroom	Indoor Operative Temperature (℃)	Prevailing mean outdoor air temperature (℃)	Air Velocity (m/s)
Upper-level	30.02	28.06	0.34
Ground-level	29.94	28.13	0.23

Figure 3 shows the range of acceptable operative temperature by using CBE Thermal Comfort tool in the naturally ventilated upper-level and ground-level school classroom. Based on Figure 3 (a), the plotted value of indoor operative temperature and prevailing mean outdoor air temperature shows that it is in the range of acceptable operative temperature. The value obtained does not comply with ASHRAE Standard 55-2017 for both 80% and 90% acceptability limits. It also indicated that the naturally ventilated upper-level school classroom is too warm for the students to occupy it and may cause discomfort for them.

Based on Figure 3 (b), the plotted value of indoor operative temperature and prevailing mean outdoor air temperature shows that it only complies with ASHRAE Standard 55-2017 when it is in 80% acceptability limits while it does not comply with the standard in 90% acceptability limits. It also indicated that only 80% of the students felt comfortable in the naturally ventilated ground-level school classroom. The result may be different from the upper-level classroom as the ground-level classroom had lower indoor operative temperature compared to the upper-level classroom. Although the adaptive charts show that both naturally ventilated school classroom is not comfortable for most of the students to occupy them, the exact thermal sensation votes of the students must be assessed too. The exact thermal sensation votes and thermal acceptability of the students can be assessed through the questionnaire that has been distributed to them during the field measurement.

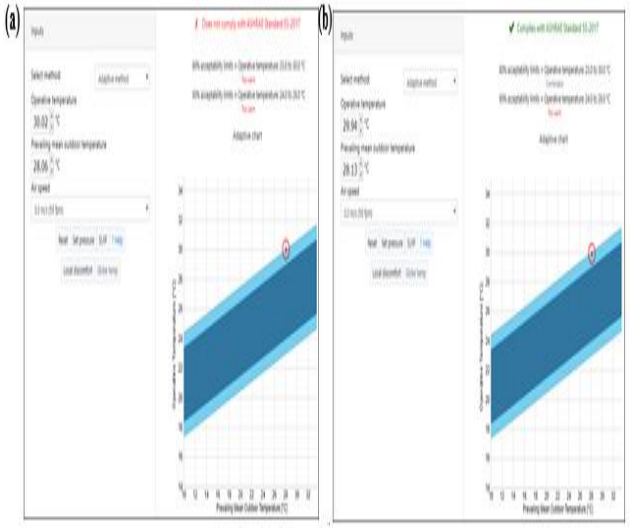

Figure 3: Adaptive chart of naturally ventilated (a) upper-level; (b) ground-level school classroom

4.2 Questionnaire Data of Upper-level School Classroom

Figure 4 shows the bar chart of the thermal sensation votes (TSV) of students and Figure 5 shows the pie chart of thermal acceptability of the students in the naturally ventilated upper-level school classroom.

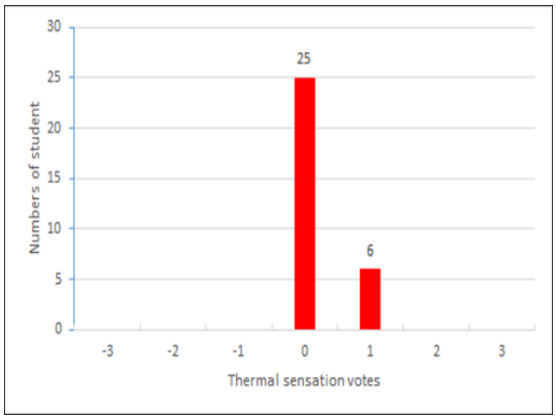

Figure 4: TSV's bar chart of students in upper-level classroom

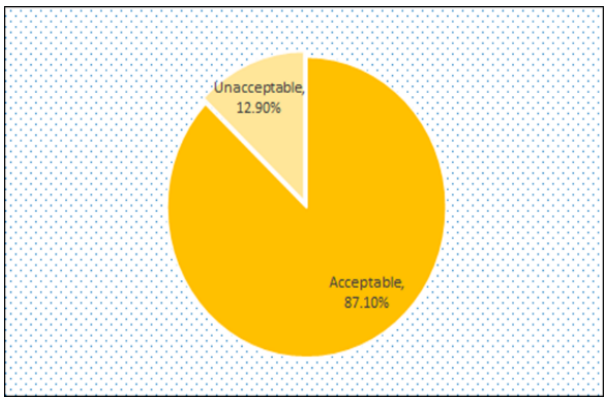

Figure 5: Thermal acceptability's pie chart of students in upper-level classroom

The total number of students in the upper-level classroom are 31 students. Based on Figure 4, for thermal sensation votes the bar chart shows 25 students felt neutral as they are occupying the classroom. The other 6 students felt slightly warm. From the bar chart, it also indicated that the students have different preferences for their thermal sensation. The students that felt slightly warm most likely are the students that sat near the window where the area affected by the heat of sunlight. In summary 80.6% of the students felt neutral and 19.4% felt slightly warm. However, based on Figure 5, the pie chart shows only 12.9% of the students did not accept the current temperature in the naturally ventilated upper-level school classroom and 87.1% accepted it.

Using Equation (1), the mean TSV value for the students in this classroom is +0.19. The value shows that classroom is thermally comfort according to ASHRAE Standard-55 2017. Comparing with the adaptive chart from Figure 3 (a), the data showed different result. The physical measurement showed less than 80% of acceptability whereas from subjective measurement, the result shows 87% of acceptability. This is because most of the regulation in ASHARE Standard 55-2017 is applicable to the adults only and it may be slightly different for the children as they may perceive thermal sensation differently from the adults.

4.3 Questionnaire Data of Upper-level School Classroom

Figure 6 shows the bar chart of the thermal sensation votes (TSV) of students and Figure 7 shows the pie chart of thermal acceptability of the students in the naturally ventilated ground-level school classroom.

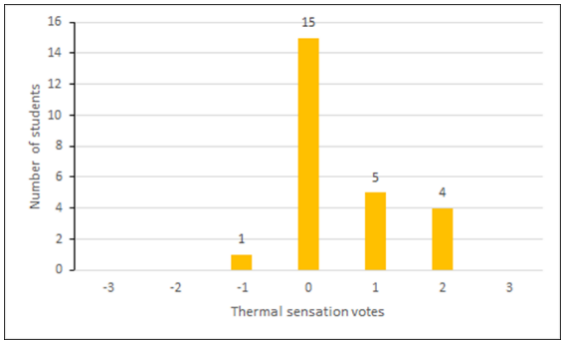

Figure 6 : TSV's bar chart of students in ground-level classroom

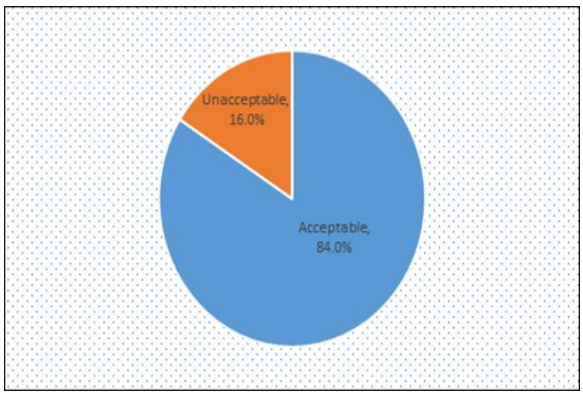

Figure 7 : Thermal acceptability's pie chart of students in ground-level classroom

The total number of students in the ground-level classroom are 25 students. Based on, Figure 6 for thermal sensation votes the bar chart shows 15 students felt neutral, 5 students felt slightly warm, 4 students felt warm and only 1 student felt slightly cool. The students that felt warm most likely are the students that sat near the window and the sunlight shone directly at them. In summary, 60% of the students felt neutral, 20% felt slightly warm, 16% felt warm and 4% felt slightly cool. From Figure 7, the pie chart shows that 16% of the students did not accepted with the current temperature of the naturally ventilated ground-level school classroom at that time and the others 80% accepted. 16% of the students are the 4 students that felt the classroom warm for their thermal sensation votes.

Using Equation (1), the mean TSV value for the students in this classroom is +0.48. The value shows that classroom is thermally comfort according to ASHRAE Standard-55 2017. Comparing with the result obtained from the adaptive chart from Figure 3 (b) and the data obtained from the questionnaire, there is a slight difference between the data. The difference is the adaptive chart indicated 80% acceptability of thermally condition for the students in the classroom whereas data from questionnaire shows 84% acceptability of the students. As stated before, this may occur as children perceived thermal sensations differently from the adults.

4.4 Summary of Results from Physical and Subjective Measurement

Table 3 shows the summary of results from both physical and subjective measurement. From the table, it shows that in subjective measurement, upper-level classroom have higher thermal acceptability than ground-level classroom because upper-level classroom have higher air velocity. Higher air velocity gave higher thermal comfort acceptability among the students in the classroom. This occurred because of when the air velocity is high in a room, the rate of heat loss from occupant's body in the room will increase. This ensure that the occupant's body can regulated body temperature at high rate and provided thermally comfort environment for the body. Another reason is the upper-level classroom have lower relative humidity than ground-level classroom. Contrary to air velocity, when relative humidity increase in a room, it will reduce the rate of heat loss from the occupant's body.

Table 3 : Summary of results from physical and subjective measurement

Classes	Thermal Acceptability		Mean TSV	Air Velocity (m/s)	Relative Humidity (%rh)
	Physical Measurement	Subjective Measurement			
Upper-level	< 80%	87%	+0.19	0.34	72.8
Ground level	80%	84%	+0.48	0.23	73.5

5. Conclusions

As a conclusion, the objectives of the study to conduct thermal comfort field study among school students in naturally ventilated classrooms and assessing thermal comfort satisfaction among the investigated school students based on ASHRAE Standard 55 were achieved. The physical measurement and subjective measurement which is questionnaire session were conducted in naturally ventilated school classrooms at Sekolah Kebangsaan Jelutong, Parit Raja. The natural ventilated school classrooms were separated into two, upper-level and ground-level classroom. The data of parameters collected during physical measurement were relative humidity, air velocity, air temperature, mean radiant temperature and prevailing mean outdoor temperature. The question for the questionnaire consisted of thermal sensation votes (TSVs) that were cast on a seven-point thermal sensation scale and the acceptability of the subjects regarding the classroom current temperature.

For the upper-level school classroom, the subjective measurement results obtained surprisingly 87% of the students accept thermal condition of the class even though the indoor operative temperature of the classroom is 30.02℃. However, from the physical measurement, thermal condition of the classroom does not comply with ASHRAE Standard 55-2017 and indicated the class was too warm for the students. For the ground-level school classroom, subjective measurement results obtained showed that 84% of the students accept thermal condition of the classroom with the indoor operative temperature of 29.94℃. This is in the agreement from the result obtained from the physical measurement which resulted in 80% acceptability of thermal condition. The result from subjective measurement also showed that female students have higher thermal sensation vote's value than the male students as their clothing insulation value slightly higher from the male. Comparing both of the classroom, upper-level classroom have higher thermal acceptability than ground-level classroom with the difference of 3% in value. The difference may influenced by the air velocity and relative humidity in the classroom. Upper-level classroom have higher air velocity and lower relative humidity than the ground-level classroom where it can increase the rate of heat loss from the occupant's body.

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