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Pilot Study on Investigation of Thermal Sensation Votes (TSV) and Students' Performance in Naturally Ventilated Classroom

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Abstract Thermal comfort is essential for students' wellbeing, health, and performance. A conducive classroom must consider the acceptable range of heat and its impact on student performance. The study aims to conduct a pilot test for the determination of thermal acceptability and student performance in existing Malaysian classrooms using physical and subjective assessments. The methodology requires physical measurement using KIMO AMI 310 instrument, as well as subjective assessment via satisfaction survey adapted from ASHRAE 55 and performance assessment adapted from WHO Neurobehavioral Core Test Battery (WHO NCTB). Physical measurement parameters, such as indoor temperature, air velocity, relative humidity, and prevailing mean outdoor temperature, were measured in parallel with subjective assessment of thermal acceptability and performance assessment. Three days of data collection were conducted in the secondary school located in Endau, Johor. There are three classes involved with a total of 46 students. Each class was equipped with two ceiling fans and both ceiling fans were regulated to the speed of four. The overall physical and subjective assessment procedure took approximately 60 minutes per classroom. The findings showed that all the investigated classes were in the range of acceptable operative temperature and complied with ASHRAE Standard 55 for both 80% and 90% acceptability limits. Pearson correlation analysis showed a small positive relationship between thermal sensation vote (TSV) and learning performance was obtained. The results also showed a higher performance score at the TSV value of -1 suggesting the students tend to have higher performance scores when they voted feeling slightly cool. Thus, the results of the pilot test gave new insight into the effective method to improve the methodology for the actual data collection.

Keywords Thermal Comfort, Learning Performance, Naturally Ventilated, School

1. Introduction

Malaysian energy efficiency standards based on the MS

1525: 2019 have established acceptable indoor conditions for comfort cooling in non-residential buildings. However, no comfort standard for students in the school had yet been established. Determinants of thermal comfort were assumed to be similar for both students and adults. However, metabolic rate, clothing, and limited adaptive behavior of school students may cause differences. The ASHRAE 55-2013 standard specifies an extension of the natural ventilation standard with elevated air movement up to 0.8 m/s (without personal control) and 1.2 m/s (with personal control). Malaysia has a high temperature, and high humidity level, and the usage of only ceiling fans in the school buildings may result in the need for higher air movement than the limit specified by ASHRAE 55-2013 standard. It has been established that thermal comfort is vital to students' perception, health, and performance. A conducive classroom should consider both the thermal acceptability range and its effect on the performance of the students. Both temperature and humidity greatly influence thermal comfort. Students cannot perform at their best if they feel too hot or too cold. Studies have consistently shown that students prefer cooler environments and are particularly vulnerable to the effects of higher temperatures, which in turn can impact their performance in school [1-3].

According to the Malaysian Ministry of Education statistics from 2020, there were 4,987,401 students enrolled in pre-school, primary school, and secondary school in the country [4]. Permission from the teacher gives students difficulties to make changes to the environment or think efficiently. School uniform policies often limit their ability to adjust clothing values. Their willingness to adjust activity levels is restricted during class hours because most classes require them to sit. When it comes to temperature fluctuations, students' physiology and psychology are immature, resulting in weak self-control.

Natural ventilation schools are largely understudied, especially in the tropics. The government's school buildings in Malaysia were built in almost similar shapes, designs, and facilities. Most Malaysian classrooms have historically depended on a combination of cross-ventilation and mechanical ventilation via ceiling fans only. There is no air conditioning installed in these classrooms. Besides that, school uniform in Malaysian public school is compulsory. Thus, a Malaysian school classroom study is necessary to evaluate students' thermal acceptability range (temperature, humidity, and preferred velocity) and its relationship to the students' performance. Thermal comfort is becoming an important necessity in educational buildings, as it is in office buildings, to allow students to learn effectively. Studies have indicated that classroom thermal efficiency improves student performance [5].

Program Transformasi Sekolah 2025 (School Transformation Program) (TS25) under the Malaysian Ministry of Education had highlighted one of the objectives is to provide an effective learning environment in schools. One of the aspects, of an effective learning environment in the classroom, should consider both the thermal acceptability range and its effect on the performance of the students. Thermal comfort has been proven to be important to students' wellbeing, health, and performance. Many studies have been conducted on the thermal comfort of naturally ventilated classrooms [8-10]. As a result, a comfortable and conducive classroom should include both the thermal acceptable range and its impact on student performance.

Thus, the aim of this study is to conduct a pilot test for the determination of thermal acceptability and student performance in existing Malaysian classrooms using physical and subjective assessments. This pilot test aimed to assess the designed methodology and came out with improved and effective data collection strategies for the actual data collection.

2. Materials and Methods

The pilot study was conducted in December 2021 for three consecutive days at one of the secondary schools located in Endau, Mersing in Johor state. Endau is located on the northern tip of east Johor (southern Peninsular Malaysia). The coordinate is 2.6522 °N, 103.6225 °E and the highest and lowest temperatures in December 2021 were 30.33 ℃ and 25.00 ℃ respectively with an average relative humidity of 77%.

2.1. Physical Assessment

The investigated secondary school has students ranging from 13 to 17 years old. Three classes were identified for the pilot test named Class A, B, and C. The location of the Class B and C is on the second and third floors of a four-story building, while Class C is on the ground floor of a two-story building as indicated in Figure 1. Overall students who took part in the study were 46 with Classroom A 14 students (male only), Classroom B 20 students (5 male and 15 female), and Classroom C 12 students (4 male and 8 female). All these respondents were 17 years old. These students wear school uniforms ranging from sports attire (long pants and short sleeves t-shirt for male and non-muslim female students, long pants and long sleeves t-shirts with headscarves for Muslim female students) and school uniforms (long pants and short sleeves shirts for male students, knee-length pinafore dress with short sleeves for the non-muslim female students and baju kurung with headscarves for Muslim female students). The clothing of the students was recorded for the clo value estimation.

Two units of KIMO AMI 310 thermal comfort instruments were used in collecting the physical measurement for both indoors and outdoors. Both physical measurements were conducted based on ASHRAE 55 standard. The indoor instrument measured continually the mean radiant temperature, air temperature, air velocity, and relative humidity. The outdoor device measured the prevailing mean outdoor temperature continually at a sampling point on the outside corridor of the investigated class. The devices automatically recorded every one minute and the duration of the physical measurement was 60 minutes [11]. The instruments were set at one sampling position inside the classroom. Following class II protocols, the instruments were placed 0.6 m above the ground and in the middle of each room [11,12].

The prevailing mean outdoor temperature was measured with a KIMO AMI 310 with a hygrometry probe. It is the mean daily outdoor air temperatures of all three consecutive days during the data collection. Figure 2 shows the physical measurement set up in indoor and outdoor classrooms.

The data obtained from the physical assessment was analyzed using the online Thermal Comfort Tool developed by the Center for The Built Environment (CBE). The tool was set based on ASHRAE 55 thermal comfort for naturally ventilated space standards. The operative temperature (t_o) can be determined using the average air temperature (t_a) and mean-radiant temperature (t_r). The following formula 1 can be used to calculate the operative temperature (t_o):

$$t_o = At_a + (1 - A)\, t_r \tag{1}$$

where, constant A can be selected from the following values as a function of the relative air speed, v_r as shown in Table 1.

Figure 3 shows the recommended operative temperature ranges for naturally ventilated space based on ASHRAE 55 standard.

2.2. Subjective Assessment

In this study, there are two types of subjective assessment were conducted: thermal perception survey and performance assessment. Figure 4 shows the overall subjective assessment procedure, which takes approximately 60 minutes per classroom. Both the physical and subjective measurements were conducted simultaneously at the same time. The pilot test was conducted with a ceiling fan speed regulator set at speed four (minimum speed is one and maximum speed is five). 46 students took part in this study and the students were given a detailed explanation of the experimental setup and methods, as well as instructions on how to complete the questionnaire and finish the performance test. During data collection, students were asked to enter the classroom and sit idle for 15 minutes to adapt to the indoor environmental condition. Based on the previous researchers, 15 minutes was the minimum time for the adaptation process because, in naturally ventilated buildings, the students' preferences and expectations for a comfortable thermal environment vary with the change in outdoor temperatures or seasons [13]. Next, students need to answer the thermal comfort satisfaction survey for 10 minutes. Lastly, the performance assessment took approximately 35 minutes. Once all activities had been done, the students were free to leave the classroom.

Table 1. Values of a based on the function of the relative air speed [8]

v_r	<0.2 m/s (<40fpm)	0.2 to 0.6 m/s (40 to 120 fpm)	0.6 to 1.0 m/s (120 to 200 fpm)
A	0.5	0.6	0.7

(a) **(b)**

Figure 1. (a) Location of classes B and C; (b) Location of class A

(a) **(b)**

Figure 2. (a) Position of the instrument (outdoor); (b) Position of instrument (indoor)

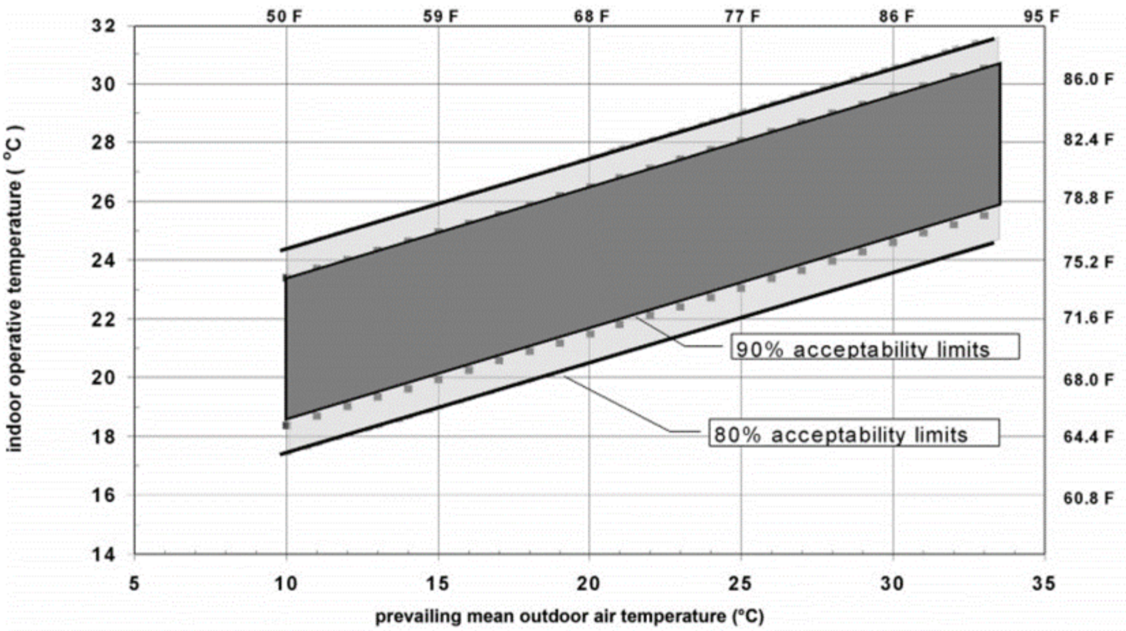

Figure 3. The recommended operative temperature (to) ranges for naturally ventilated space [8]

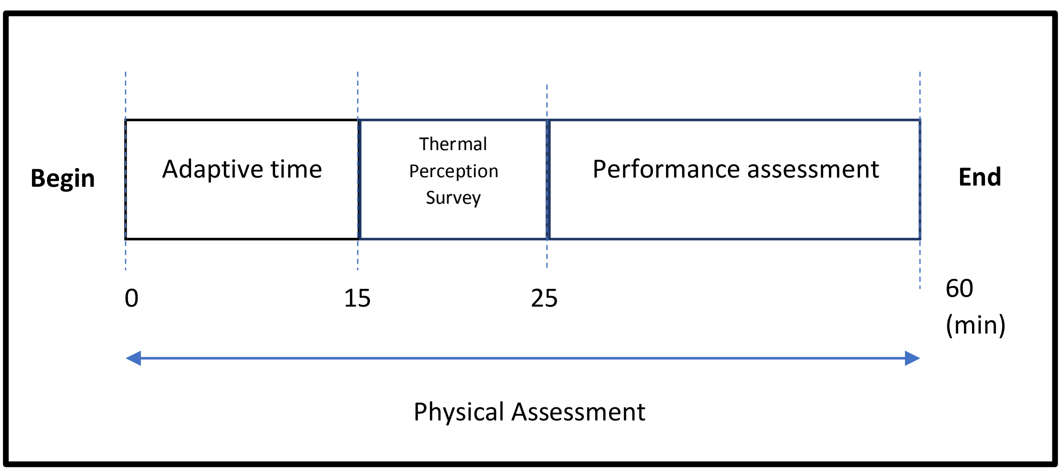

Figure 4. Subjective assessment procedure

2.2.1. Thermal Perception Survey

The survey used in this study was divided into two sections. Part 1 aimed to gather general information about the students (gender, age, and availability of air-conditioners in their house, do they prefer the overall condition of the classroom) and asked the respondent to mark their sitting position in the classroom. Part 2 of the survey was meant to gather information about students' subjective perceptions of the classroom's thermal comfort and satisfaction. The survey was conducted in accordance with BS EN 7730:2005 [12]. The questionnaire consists of a seven-point Likert scale to observe the thermal comfort of the classroom which includes the satisfaction survey for different elements such as air temperature, humidity, wind speed, solar radiation, respondent comfort, and thermal satisfaction level, as well as asking the elements that influence the classroom comfort level based on the respondent's opinion as summarize in Table 2.

Data obtained from the questionnaire were used to obtain the mean of thermal perception vote by using Equation 2. The value of each vote is as tabulated in Table 3.

Data obtained from the questionnaire were used to obtain the mean of thermal perception vote by using Equation 2.

$$Mean = \frac{\left(n_1 \times x_1\right) + \left(n_2 \times x_2\right) + \left(n_n \times x_n\right)}{N} \quad (2)$$

where n = Number of students

x = Value of vote

N = Total number of students

The value of each vote is as tabulated in Table 3.

2.2.2. Performance Assessment

The learning performance test included two tasks related to two domains of attention and memory learning. The criteria of the task were followed by the Neurobehavioral Core Test Battery [14]. The description of each test is shown in Table 4. The score and time taken on each test question were recorded to calculate the accuracy and reaction time. Then, the performance test score was calculated by using Equations (3) and (4).

Table 2. Design of Part 2 questionnaire questions for thermal perception

Variable	Questions
Thermal sensation	How do you feel about the temperature/humidity/ wind speed/ sunlight radiation at the moment? temperature: very cold, moderate cold, slightly cold, normal, slightly hot, moderately hot, very hot humidity: very moist, moderately moist, slightly moist, normal, slightly dry, moderately dry, very dry wind speed: very fast, moderately fast, slightly fast, normal, slightly hot, moderately hot, very hot sunlight radiation: very not disturbed, moderate not disturbed, slightly not disturbed, normal, slightly disturbed, moderate disturbed, very disturbed
Thermal comfort	Are you comfortable at the moment? Very uncomfortable, Comfortable, slightly comfortable, Neutral Slightly comfortable, Comfortable, Very comfortable
Thermal preference by element	Choose the elements that most influence your comfort in the classroom. Air temperature, Humidity, Sunlight, Air velocity
Thermal satisfaction	Are you satisfied with this classroom? Very unsatisfied, Unsatisfied, Slightly unsatisfied, Neutral, Slightly satisfied, Satisfied, Very satisfied

Table 3. Thermal scales and given values

Variable	Scales and Given Real Number
Thermal sensation	(-3) Cold, (-2) Cool, (-1) Slightly cool, (0) Neutral, (+1) Slightly warm, (+2) Warm, (+3) Hot
Thermal comfort	(-3) Very uncomfortable, (-2) Uncomfortable, (-1) Slightly uncomfortable, (0) Neutral, (+1) Slightly comfortable, (+2) Comfortable, (+3) Very comfortable
Thermal satisfaction	(-3) Very unsatisfied, (-2) Unsatisfied, (-1) Slightly unsatisfied, (0) Neutral, (+1) Slightly satisfied, (+2)Satisfied, (+3)Very satisfied

Table 4. The detail for the categories and task type of performance test [15]

Category	Task Type	Description
Attention	Simple reaction test	Simple reaction time (SRT) tests, in which subjects answer as quickly as possible when a stimulus occurs, are among the most fundamental measures of processing speed.
Memory-learning	Digit span forward and backward test	Digit Span Forward needs the student to type the numbers in the same order as they are appearing on the tablet, whereas Digit Span Backward needs the student to type the digits in the opposite direction after they appeared.

Simple Reaction Test

$$Standard\ score = \left[z\ Score\ (\ reversed) \times 10 \right] + 50 \quad (3)$$

Digit Span Test

$$Standard\ score = \left[z\ Score\ \times 10 \right] + 50 \quad (4)$$

where:

$$z\ Score = \frac{Adjusted\ Score}{Standard\ Deviation}$$

$$Adjusted\ Score = Raw\ Score\ -\ Mean$$

To verify the quality of the responses and eliminate the influence of self-learning skills, students of the same age were chosen to participate in this performance assessment. This is in line with the method suggested by Wang [16].

2.3. Statistical Analysis

IBM SPSS Statistics 26 software was used for this statistical analysis. The data for the 46 students were evaluated, and the means and standard deviations for the data and within the groups for each test were calculated.

First, the Shapiro-Wilk test was used to determine if the performance assessment data are normally distributed. SPSS performs two normality tests which are Kolmogorov-Smirnov and Shapiro-Wilk. If the significance value is bigger than the alpha value ($\alpha = 0.05$), there is no reason to consider the data deviates significantly from a normal distribution. It may reject the null hypothesis that it is not normal.

Second, Pearson correlation coefficients were calculated to investigate the relationships between variables. The correlation coefficient must always be between - 1 and 1. The stronger the relationship between the variables, the greater the absolute value of the coefficient [13]. Then, compare the p-value to the significance level to see if the correlation between variables is significant. In most situations, the significance level (α) is 0.05 or 0.01. At a 5% level of significance, the probability of correlation exists when no correlation exists is not more than 5 out of 100. If the P-value is less than or equal to α, the correlation is statistically significant.

3. Result and Discussion

3.1. Determination of Thermal Comfort Using CBE Thermal Comfort Tool

The calculated physical parameters of each investigated class are as tabulated in Table 5. Classroom A had the highest indoor operative temperature which was 29.9 ℃, while 28.1 ℃ for classroom B and the lowest operative temperature was 27.8 ℃ for classroom C. The location of classroom A was on the ground level while classrooms B and C were located on the third and fourth levels. The indoor operative temperature was closely related to the outdoor temperature of each of the classrooms.

The values obtained have complied with ASHRAE Standard 55-2020 for both 80% and 90% acceptability limits for naturally ventilated spaces suggesting the environment was comfortable and suited for student learning in all three classrooms.

Table 5. Physical parameters for each classroom

Classroom	Indoor Operative Temperature (℃)	Prevailing mean outdoor air temperature (℃)	Air velocity (m/s)
A	29.9	29.9	0.62
B	28.1	28.6	0.62
C	27.8	28.1	0.40

3.2. Thermal Perception Results

The next sub-chapter discussed the results of the thermal perception survey.

3.2.1. Thermal Sensation Vote (TSVs)

Table 6 shows the mean TSV values for each class and average TSV for all classes. The data analysis of TSV indicated that the average mean thermal sensation vote for all classes was between "slightly cool" and "neutral," with a mean value of -0.68 for all classes assessed. Class A showed the lowest value of TSV compared to other classes. This is in the same agreement as Class A had the highest air velocity value, which was 0.62 m/s. All respondents from Class A were also male, which probably affected the votes because their type of cloth had a lower value of clothing insulation compared to female students.

Table 6. Thermal sensation vote by classroom

Classroom	Mean Thermal Sensation Vote
A	-1.07
B	-0.55
C	-0.42
Average for all classes	-0.68

3.2.2. Thermal Comfort Votes (TCVs)

Table 7 shows the mean TCV values for each class and average TCV for all classes. The calculated thermal comfort votes, as shown above, indicated that the average mean thermal comfort vote for all classes was between "slightly comfortable" and "comfortable," with a mean value of 1.63 for all classes assessed. This vote proves that the physical measurement that was interpreted into the adaptive chart for each class was valid because it complied with ASHRAE Standard 55-2013 for both 80% and 90% acceptability limits where most of the students predicted to feel comfort in the classroom.

Table 7. Thermal comfort vote by classroom

Classroom	Mean Thermal Comfort Vote
A	2.14
B	1.75
C	1.00
Average for all classes	1.63

3.2.3. Factors Contributed to Classroom Comfort

Figure 5 shows the percentage of factors that contributed to the classroom comfort voted by the students. It shows that 52.2% of students agreed that air velocity the most influences their comfort in the classroom. 28.3% of students prefer the air temperature while 13% and 6.5% of students prefer the humidity and sunlight. From the votes, air velocity was an important element among the others, and it affects the students' thermal condition.

3.3.4. Thermal Satisfaction Vote

The thermal perception survey also asked students to specify their satisfaction with thermal in their classroom. The students were given the following options: very unsatisfied, unsatisfied, slightly unsatisfied, neutral, slightly satisfied, satisfied, or very satisfied. Figure 6 summarizes the results. The findings indicate that 76.1% of students were satisfied with the thermal of the classroom. Table 8 shows the calculation of thermal satisfaction votes. It indicated that the average mean thermal satisfaction vote for all classes was between "slightly satisfied" and "satisfied," with a mean value of 1.59 for all classes assessed. The results were aligned with the results of predicted thermal comfort calculated from the physical parameters.

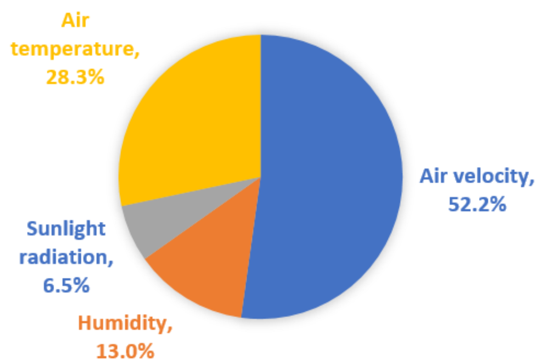

Figure 5. Percentage of factors that contributed to the classroom comfort voted by the students

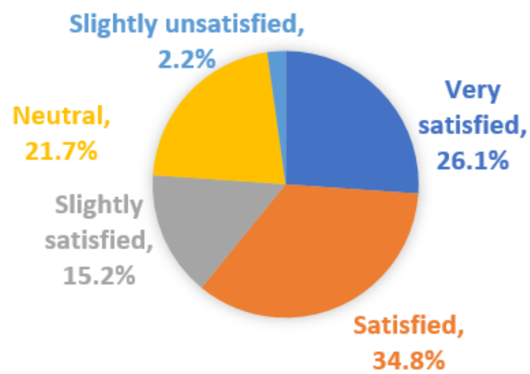

Figure 6. Percentage of thermal satisfaction votes for all students

Table 8. Thermal satisfaction vote scale

Classroom	Mean Thermal Satisfaction Vote
A	2.21
B	1.55
C	1.00
Average for all classes	1.59

3.3. Mean Thermal Sensation Vote vs Performance Assessment by Class

Figure 7 shows the relationship between TSV and performance assessment scores. Both the performance assessment score and TSV were almost linearly connected. The nearer the votes to the neutral thermal sensation votes (value: 0), the better the students' learning performance in classrooms B and C. Both classrooms B and C are located on a higher level of the building compared to classroom A which is situated on the ground level. Thus, to increase the reliability of the results, the performance test should be conducted in a similar condition classroom to exclude other factors that may influence the performance test results.

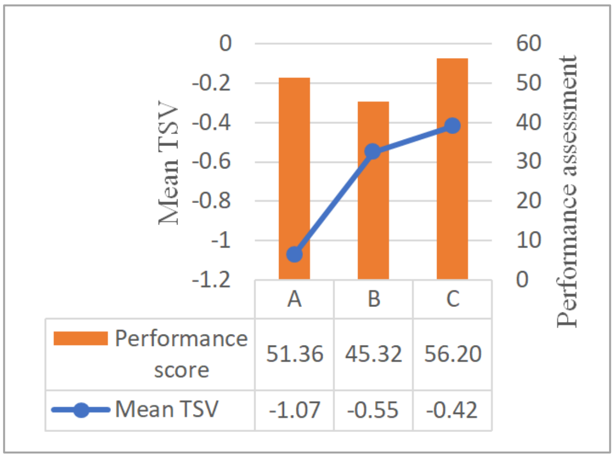

Figure 7. Mean TSV vs performance assessment by class

3.4. Statistical Analysis

Based on both the physical and subjective assessment, statistical analysis was performed to determine the relationship between TSV and the students' performance. This phase is critical to understanding the data correlation and identifying improvement strategies when conducting the actual data collection. The data was confirmed to be normally distributed and a Pearson correlation analysis was conducted to get the correlation for TSV versus the performance test score and the operative temperature versus the performance test score.

3.4.1. Pearson Correlation Analysis

Figure 8 shows the correlation between learning performance and thermal sensation vote has a Pearson Correlation Coefficient (r) value of 0.153, indicating a small positive relationship between the two variables. Additionally, the association's P value was .310, the p-value greater than 0.05 (> 0.05) is not statistically significant and suggests that the null hypothesis is strongly supported. This signifies that the null hypothesis is accepted, and the alternative hypothesis is rejected. Although statistically not significant correlation, the analysis, shows a higher performance score at TSV -1. When they vote to feel slightly cool, students tend to have higher performance scores.

Figure 9 shows that the correlation between learning performance and the operative temperature has a Pearson Correlation Coefficient (r) value of -0.107, indicating a small negative relationship between the two variables. Moreover, the association's P value was .477, the p-value greater than 0.05 (> 0.05) is not statistically significant and suggests that the null hypothesis is strongly supported. This signifies that the null hypothesis is accepted and the alternative hypothesis is rejected. It's critical to know how well two variables relate to one another. A statistically significant finding cannot establish the validity of a study hypothesis (as this implies 100 percent certainty).

Correlations

		Thermal Sensation Vote	Learning Performance
Thermal Sensation Vote	Pearson Correlation	1	.153
	Sig. (2-tailed)		.310
	N	46	46
Learning Performance	Pearson Correlation	.153	1
	Sig. (2-tailed)	.310	
	N	46	46

Figure 8. Pearson correlation between TSV and learning performance

Correlations

		Learning Performance	Operative Temperature
Learning Performance	Pearson Correlation	1	-.107
	Sig. (2-tailed)		.477
	N	46	46
Operative Temperature	Pearson Correlation	-.107	1
	Sig. (2-tailed)	.477	
	N	46	46

Figure 9. Pearson correlation between operative temperature and learning performance

Both of the relationships were not statistically significant. It can be countered by increasing the sample size, the standard error will decrease, or the difference between the sample statistic and the hypothesized parameter is increased, the p-value lowers, making it more likely that the null hypothesis is rejected. For the actual field study, the sample size needs to be increased to obtain a more precise result.

3.5. Improvement of the Actual Data Collection

From the pilot test, several improvements need to be considered.

- Student cloth is one of the essential factors in this study. On the day of the pilot test, the students' cloth was not uniform. Some of them wear school attire, and others wear sports attire. The difference in clothing insulation values will affect the results. For the actual field study, the researcher needs to include a question about the students' cloth in the satisfaction survey. It's easier for the researcher to record the type of cloth worn by the student on an actual day.
- The thermal perception survey needs to be improved by assigning the value from -3 to +3 on the seven-point Likert scale to match with the seven-point of thermal comfort scale. The illustration in the survey paper also can be enhanced by putting color indicators for example; blue for cold and red for the hot option.
- The pilot test was run simultaneously for physical and subjective assessment in each classroom. There was a fluctuation in air temperature which was closely related to the prevailing outdoor mean air temperature. There were also difficulties to analyze the performance score since it was conducted in a different classroom. It is suggested to divide the actual data collection into two main data collection.
  (i). First data collection only focused on physical data measurement and thermal perception survey. This first data collection will be able to correlate TSV with the operative temperature in different classes.
  (ii). The second data collection will focus on the performance test that will be carried out in the same classroom for all the respondents along with the physical measurement. This second data collection will be able to correlate operative temperature with the performance score.

4. Conclusions

As a result, the study fulfilled its objectives of conducting a pilot test for the determination of thermal acceptability and student performance in existing Malaysian classrooms using physical and subjective assessments. Three classes are involved in this pilot test. The physical parameters (mean radiant temperature, air temperature, air velocity, relative humidity, and the prevailing mean outdoor temperature were gathered during the physical measurement. The thermal perception survey includes questions about subjects' general information and students' subjective perceptions of thermal comfort. There is four variable of thermal perception such as thermal sensation votes, thermal comfort votes, thermal satisfaction votes, and thermal preference by element. All the votes are based on a seven-point Likert scale. Results of the physical measurement showed that all the classes are comfortable and suited for student learning because the value obtained complied with ASHRAE Standard 55-2020 for both 80% and 90% acceptability limits. From the subjective assessment, the thermal comfort votes obtained that 78.3% of the students are comfortable in the classroom with an average indoor operative temperature is 28.6 ℃.

The result from SPSS showed that the Pearson Correlation Coefficient (r) value for the relationship between thermal sensation and learning performance is

0.153. While the (r) value for the indoor temperature and learning performance is 0.106. Both relationships correlate, but it is considered weak because of the small (r) value. The result may be influenced by the size of the sample. It can be concluded that the results from the pilot test helped to give significant insight and ideas for modification of the research methodology to ensure reliable data collection in the actual study.

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