Factors Affecting Thermal Comfort of Elementary Schools’ Students in Makassar

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Abstract. The article aims to analyze the most affecting thermal environmental factors on students’ thermal comfort in elementary schools. The questionnaire has been collected from 1,111 students. The one-minute interval of data measurements was carried out in the 33 classrooms at six primary schools in Makassar. Environmental data involved measurements of air temperature, globe temperature, air velocity, and relative humidity. Students wrote down their personal data and their response to the thermal environments of classrooms in the questionnaire sheets. The results show that the most affecting factor of thermal comfort of students is operative temperature ($T_o$). Based on the students’ thermal sensation votes, the operative temperature ranges from 29.1 to 30.0 °C is recommended to provide a comfortable condition for students to learn more successfully in the naturally ventilated primary schools’ classrooms. This result is slightly lower than the neutral temperature obtained from the regression between actual votes and the operative temperature, which was 30.2 °C. The results agree with the neutral temperature calculated using the revised Humphreys adaptive model which give the result of 29.4 °C. The second variable that has a significant effect on the students’ thermal comfort is air velocity. The students felt comfortable at air velocity at about 0.25 m/s and also at air velocity more in the ranges of 1.00 to around 1.50 m/s.

1. Introduction

It is essential to provide good environmental conditions in the classrooms for students that enable them to learn more effective and successfully [1-3]. One of these environmental conditions is thermal comfort. ASHRAE standard 55 [4] defines thermal comfort as “the state of mind that expresses satisfaction with the surrounding environment.” Fanger [5] describes three main factors determining thermal comfort of occupants. These factors are including thermal environments, individual, and other contributing factors. Environmental factors involve air temperature, air velocity, relative humidity, and radiant temperature. Individual factors involve clothing index and type of activity. Food and drink, acclimatization, body shape, subcutaneous fat, age and sex, and state of health are among contributing factors.

Several thermal comfort studies of students in the elementary schools have been carried out worldwide. The most updated studies in elementary schools [6-10] will be discussed. The studies analyzed different and broad aspects of thermal comfort in the elementary schools. Kim and de Dear [6] analyzed the thermal comfort expectations and behavior adaptation of students in secondary and elementary schools in Australia. Kim and de Dear found that among many other adaptive options, air...
conditioning is the most favorable adaptation method. Ali and Al-Hashlamun [7] assessed the thermal environment of indoors at different prototypical school buildings in Jordan. They compared the indoor thermal comfort between new and old schools. They found that the new school buildings provide a more satisfactory thermal environment than the old one. Jindal [8] presents a study of thermal comfort in naturally ventilated classrooms in India. Jindal found that there was a variation of comfortable classrooms between winter and summer session. Jiang et al. [9] explain a study on learning performance of students and thermal comfort of elementary schools in China. Jiang et al. [9] found that the environmental factors were strongly affecting the students’ votes on overall indoor environmental quality (IEQ). Moreover, the learning performance of students is affected by all IEQ complaints and there was a good correlation between the number of complaints and the learning performance. Trebilcock et al. [10] discusses an adaptive thermal comfort taken from a field study in elementary schools in Chile. They found that socio-economic background of students affected the their thermal comfort votes.

In Indonesia, several studies assessing thermal comfort in educational buildings including primary schools [11-16] have also been carried out. The previous articles based on Makassar data have highlighted that even though the temperature of classrooms was hot, students in primary schools [13], secondary schools [12], and university [14] were mostly felt comfortable with around 80% of thermal acceptance. This phenomenon has led to another study that analyzed the application of adaptive model thermal comfort [15]. Using data collected from six elementary schools in Makassar, Hamzah et al [15] found a good agreement between the neutral temperature originated from actual votes and the one calculated from adaptive model [17-19].

This article aims to analyze the most affecting thermal environment factors that influence the students’ thermal comfort in naturally ventilated classrooms in the elementary schools located in Makassar, Indonesia. The study is focused on the effect of each thermal environmental factors i.e. operative temperature, relative humidity, and air velocity on the students’ thermal comfort. Besides, the integrated effect of the thermal environment variables is also analyzed and discussed in this article.

2. Research Method

2.1. Data Collection

Data have been collected from six nominated primary schools located in the city of Makassar, Indonesia. The data collection involved 33 classrooms and 1,111 students. The measurements and questionnaires data have been discussed in the previous conferences [13, 15]. The study used two protocols to collect data as follows:

- The objective surveys or measurements were carried out to record the thermal environment parameters and also the personal data of respondents. The one-minute interval of data measurements was carried out in the 33 classrooms at six primary schools in Makassar. The survey made use of one set of LSI TC, a multi logger of thermal comfort and four Hobo data-loggers. The LSI TC was manufactured by LSI-Laistem Italy. In this survey, The LSI TC connected with three sensors. Those sensors consist of one sensor (BST131) for measuring globe temperature, one sensor (BSU102) for measuring the air temperature and relative humidity, and one sensor (BSU121) for collecting wet bulb temperature. Besides, the measurements of thermal environments were also recorded by Hobo data-loggers, which was developed and manufactured by Onset in the United States. There were four standard Hobo loggers (Hobo-1) and two Hobo loggers (Hobo-2) with the external sensor were used in the surveys. Hobo-1 measured and collected air temperature and relative humidity. The external sensor attached in the Hobo-2 was a wire anemometer, which used to collect the velocity of air inside the classrooms. All sensors were placed in the six locations inside the classrooms at about 1 m above the floor level, following the same high as in Wong and Khoo [20]. The arrangement of instruments in a typical classroom is illustrated in Figure 1. The instruments used in this article has been explained in Hamzah et al. [13, 15]. Because of the number of LSI TC instruments are limited, two environmental parameters could not be measured at the six positions. The MRT was only measured and recorded.
at position A, and the air velocity at positions A and B. The position of instruments in the classrooms has been also explained in Hamzah et al. [13]. Students wrote their details of clothing data and indicated their position in the questionnaires. While the surveyors recorded the activity of students in the classrooms. The situation of typical measurement is shown in Figure 2.

• The subjective measurements or surveys were carried out to collect the students’ responses on the thermal environment conditions. This was collected by questionnaire method. The questionnaire was developed and modified based on the questionnaire used in Wong and Khoo [14] in Singapore. This modified questionnaire has also been used in the previous study in Makassar, Indonesia [11-15]. The adapted questionnaire includes seven questions. Four questions recorded the students votes on the thermal aspects (thermal sensation, comfort level, thermal preference, and thermal acceptance). The following two questions asked the students’ votes on the air velocity. The last question intended to get the students’ votes on the humidity of classrooms. This questionnaire asked the TSV of respondents in seven scales following the ASHRAE standard protocol [4], namely: cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2), and hot (+3).

Figure 1. The placement of measurement instruments in a typical classroom

2.2. Data Analysis

Spreadsheet and statistical analysis software have been used in data analysis. The mean value of environmental variables has been calculated using the spreadsheet software Microsoft (MS) Excel. The same software has also been used to generate bar-chart graphics illustrating the percentage of TSV for each environmental variable (operative temperature, air velocity, and relative humidity). The scatter plot graph and linear regression analyses have been calculated using a statistical package for social science (SPSS) version 25. The regression illustrates the graphical of respondents’ thermal sensation votes over the operative temperature ($T_o$).
3. Results and Discussion

3.1. The Effect of Temperature on the Thermal Comfort of Students

The effect of temperature on the thermal comfort of students can be assessed based on operative temperature ($T_o$). Operative temperature is equal to the average between air temperature and radiant temperature.

![Figure 3. The percentage of thermal sensation votes (TSV) based on the operative temperature ($T_o$)](image)

The distribution of students’ thermal sensation votes (TSV) in each operative temperature group is presented in Figure 3. In the temperature range of 28.1-29.0 °C, most of the students voted in the slightly cool (-1). The highest percentage of students who votes neutral (0) is in the temperature ranges 29.1-30.0 °C, followed by 31.1-32.0 °C. In temperature ranges from 29.1 to 34.0 °C, the percentage of
students votes neutral has fluctuated with a downward trend. On the contrary, the percentage of students who votes warm and hot regions (+1 to +3) is mostly increased. The highest percentage of student who felt slightly warm, warm and hot is the temperature range 33.1-34.0 °C. Based on this analysis, the temperature range of 29.1-30.0 °C is the most comfortable temperature for students in the naturally ventilated classrooms of elementary schools in Makassar. This figure is similar to the neutral temperature calculated from Humphrey’s adaptive model [17] i.e. 29.4 °C as described in Hamzah et al. [15].

Figure 4 shows the scatterplot and regression between students’ votes and the operative temperature (T₀). The formula of regression analysis between TSV and the operative temperature (T₀) is presented as follows:

\[ TSV = 0.22T_0 - 6.64 \]  \hspace{1cm} (1)

where,

- TSV = thermal sensation vote
- T₀ = operative temperature

The neutral temperature (T₀) obtained from the regression between actual votes (TSV) and the operative temperature is 30.2 °C (T₀). This figure is quite close to the neutral temperature (i.e. 29.4 °C [15]) calculated using Humphrey’s adaptive model [17].

![Figure 4. The scatterplot with regression equation between operative temperature and TSV](image)

3.2. The Effect of Air Velocity on the Thermal Comfort of Students

Figure 5 shows the percentage of thermal sensation votes (TSV) based on groups of air velocity. The air velocity is ranging from less than 0.25 m/s to more than 1.25 m/s. In the <= 0.25 m/s group, the percentages of respondents who felt slightly cool (-1), neutral (0), and slightly warm (+1) are almost similar. This indicates that the air velocity of less than 0.25 m/s has very little impact on the thermal comfort of respondents. In the 0.26-0.50 and 0.51-0.75 groups, the percentage of students who felt slightly warm (+1) is higher than those who felt slightly warm and neutral (0). This indicates that in medium air velocity group students tend to feel warm. While in the last two groups (1.01-1.25 and >1.25 m/s), the percentage of students who felt slightly warm (+1) is lower than those who felt slightly cool (-1) and neutral (0). This indicates that in the group of air velocity of more than 1.00 m/s to around 1.25 m/s, the percentage of students felt comfortable increased from previous air velocity group.
3.3. The Effect of Relative Humidity on the Thermal Comfort of Students

The effect of relative humidity experienced by students in the classrooms on their thermal comfort is presented in Figure 6. As seen in the figure, the highest percentage of students votes neutral (0) is in the humidity range in between 65.1 to 70.0%. In this group, about 35% of students were felt neutral. The highest percentage of students who felt either slightly warm (+1), warm (+2), or hot (+3) is the relative humidity range from 60.1 to 65.0%.

\[ TSV = \beta_0 + \beta_1 T_o + \beta_2 RH + \beta_3 AV = \beta_0 + 0.385 T_o + 0.049 RH - 0.29 AV - 15.006 \]  

where

| TSV  | thermal sensation vote |
|------|------------------------|
| T_o  | operative temperature   |
| RH   | relative humidity       |
| AV   | air velocity            |

Figure 5. The percentage of thermal sensation votes (TSV) based on the air velocity

Figure 6. The percentage of votes based on the relative humidity (RH)
Table 1. ANOVA of multiple regressions

| Model          | Sum of Squares | Degree of freedom | Mean Square | F      | Sig.  |
|----------------|----------------|-------------------|-------------|--------|-------|
| 1 Regression   | 144.008        | 3                 | 48.003      | 47.345 | 0.000 |
| Residual       | 1122.375       | 1107              | 1.014       |        |       |
| Total          | 1266.383       | 1110              |             |        |       |

Table 2. The coefficients of multiple regressions

| Model          | Unstandardized Coefficients | Standardized Coefficients | t      | Sig.  |
|----------------|-----------------------------|---------------------------|--------|-------|
| 1 (Constant)   | -15.006                     | -9.455                    | 0.000  |       |
| Operative Temperature (T<sub>o</sub>) | 0.385                       | 0.495                     | 11.08  | 0.000 |
| Relative Humidity (%) | 0.049                       | 0.243                     | 5.541  | 0.000 |
| Air Velocity (m/s) | -0.29                       | -0.105                    | -3.583 | 0.000 |

Equation 2 shows that the dependent variable TSV has a positive correlation with the independent variable of the operative temperature and the relative humidity. This means that the TSV will increase when the operative temperature or the relative humidity increase. Based on the comparison between the coefficient of operative temperature and relative humidity, the operative temperature will affect the thermal comfort by about eight times the effect resulted from relative humidity. The coefficient of operative temperature will give an impact on the increase or reduction of one TSV if there is an increase or reduction of three °C. The same effect will be expected from an increase or a reduction of 24% of RH.

4. Conclusion
Based on the results and discussion, it is found that the most affecting factor of thermal comfort of students is operative temperature (air temperature and radiant temperature). Based on the students’ thermal sensation votes, the operative temperature ranges from 29.1 to 30.0 °C is recommended to provide a comfortable condition for students to learn in the naturally ventilated primary schools. This result is slightly lower than the neutral temperature obtained from the regression between actual votes and the operative temperature. The neutral temperature is 30.2 °C. The results agree with the neutral temperature calculated using the revised Humphreys adaptive model. The second variable that has a significant effect on the students’ thermal comfort is air velocity. The students felt comfortable at air velocity at about 0.25 m/s and also at air velocity more in the ranges of 1.00 to around 1.50 m/s.

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