**DESIGN AND ARCHITECTURE**

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# EVALUATION OF THERMAL PERFORMANCE IN NATURALLY VENTILATED CLASSROOM AT TROPICAL CLIMATE

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***Abstract -*** A naturally ventilated classroom has a significant impact on indoor thermal performance, especially in a tropical climate. This paper presents an evaluation of thermal comfort parameter in a naturally ventilated classroom located in Malaysia. For this study, a field experiment was conducted in Behrang, Perak to measure the indoor thermal comfort parameter. There were two case study classrooms selected for the experimentation with different orientations, which are Southeast for Classroom A and Northwest for Classroom B. The field experiment was conducted in November till December 2018. Air temperature, air velocity, relative humidity and mean radiant temperature were measured in this study to evaluate the classrooms' indoor performance. At the same time, the outdoor air temperature, air velocity and relative humidity were measured concurrently. The data was collected for three days during sunny days as well as clear sky. A result of data analysis found that there is a positive relationship between outdoor and indoor temperature and outdoor and indoor relative humidity. As conclusion, this study found that an outdoor parameter influenced the indoor performance in a naturally ventilated classroom. Also, the orientation and external condition of the classroom has a significant influence on indoor thermal performance..
***Keywords -*** Thermal Comfort, Naturally Ventilated Classroom, Tropical Climate, Thermal Comfort Parameter

## 1 INTRODUCTION

An educational building should provide a comfortable and stimulating learning environment. The educational buildings are different from other building because of the use and the activities held in the building. Research regarding the thermal performance in a classroom found that the condition of the indoor environment influences the teaching and learning process as well as students' performance. Unfavourable classroom environment causes poor attendance of the students, reduce students' attention and concentration, affect students' academic achievement and distract the teaching and learning process (Mendell & Heath,2005; Corgnati et al.,2007; Toftum et al.,2015; Stazi et al.,2017). The issue of the thermal comfort condition is crucial in the naturally ventilated classroom, especially in tropical climate. Jindal (2018) stated that students in naturally ventilated classroom show dissatisfaction with the indoor environmental condition. The result corresponds with a study done by Singh et al. (2018) and Kumar et al. (2018) which found that students felt dissatisfied with their indoor environment and prefer high airspeed range in the classroom. Malaysia, as a tropical country might face a thermal comfort issue in a naturally ventilated building. The challenge is more crucial in an educational institution as there are rules of attire to be compiled by the occupants. The users of the naturally ventilated classroom might be facing difficulties to achieve their thermal comfort during teaching and learning activities. Therefore, this study aims to achieve the objectives as follows:

i) To measure thermal comfort parameter in a naturally ventilated classroom of tropical climate
ii) To evaluate the indoor thermal performance of naturally ventilated classroom of tropical climate

## 2 METHODOLOGY

The field experiment was conducted in naturally ventilated classrooms at Politeknik Sultan Azlan Shah, Behrang. This study aims to evaluate the indoor thermal performance of naturally ventilated classroom in higher educational institution which focuses more on suburban area. Due to the issue of climate change nowadays, the study of thermal comfort has remained relevant, especially in the educational institutions where natural ventilation is still used in a classroom. For this reason, Politeknik Sultan Azlan Shah was chosen as the case study due to the implementation of natural ventilation system in all classrooms as compliance to *Garis Panduan & Peraturan Bagi Perancangan Bangunan, Jawatankuasa Standard & Kos (2008)*.

Two different classrooms were selected concerning the orientation. Classroom A was oriented to South-East, while Classroom B was oriented to North-West (Figure 1). Both classrooms have less obstruction than other classrooms and have the same size, which is 9m x 9m and located 4m height from the ground. Both classrooms also have an opening in two-sided of the wall (Figure2) as the design was standardised. The experiment was conducted to collect the data of the indoor thermal comfort parameter, which are air temperature, relative humidity, mean radiant temperature and air velocity. Together, the outdoor environmental parameter was collected at the same time, which includes air temperature, air velocity and relative humidity (Wagner, 2007). The time setting of the data collection for both indoor and outdoor parameter was logged in parallel. Both data were collected in three days during clear sky and sunny days (Ismail, 2010). The field experiment was conducted starting from November till December 2018 by taking into account the semester break, so that the classroom will be unoccupied during the experiment. The data was collected for 8 hours, which started from 8.30am to 4.30pm by considering that the classrooms are being used for 8 hours a day. There are no specific selected days to conduct the experiment because the weather condition has no significant differences from one day to another as Malaysia is located in a tropical region experiencing hot and humid climate throughout the year. Supported to that, Sabarinah (2006) (as cited in Abd Wahab et al., 2016) mentioned that hot and humid climate provide Malaysia with almost uniform temperature throughout the year with an average temperature between 26°C to 37°C. Previous research also found that there were averagely high air temperature, relative humidity and solar radiation in a year with the monthly mean maximum temperatures vary from 33.5°C in March and April to 31.9°C in December with yearly mean air temperature of 27°C (Makaremi et al.,2012; Ghaffarianhoseini et al.,2015; Ghaffarianhoseini et al.,2019). Based on the global radiation data derived from Malaysian Meteorology Department, the reading of global radiation in November to December 2018 shows a similar trend for the two mentioned months(Figure 3) which indicates that the weather does not have big difference from one day to another. The reading of global radiation was recorded for 24 hours in November and December 2018 from the nearest station of the location of this study. The station was located at Hospital Kuala Kubu Baru (03° 34' N, 101° 39' E).

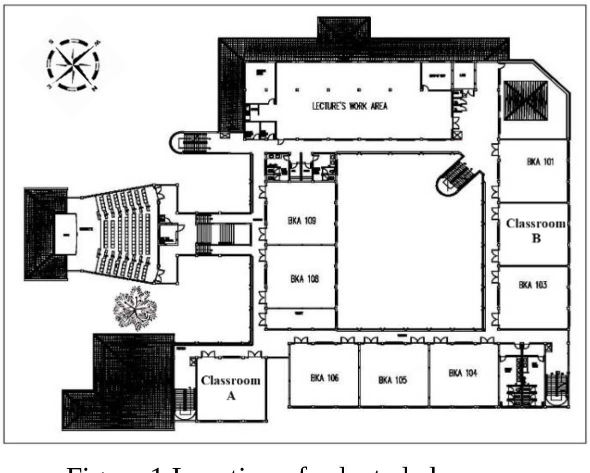


Figure 1 Location of selected classroom

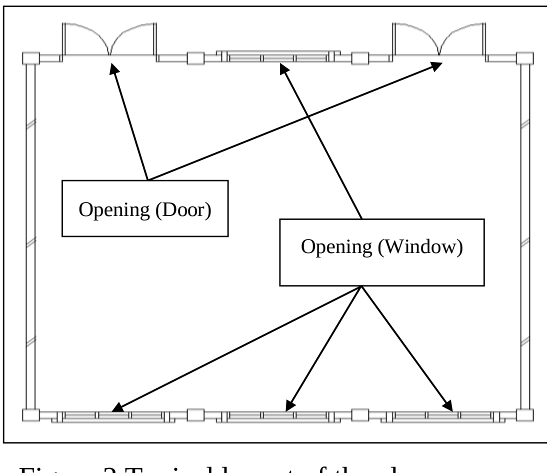


Figure 2 Typical layout of the classroom

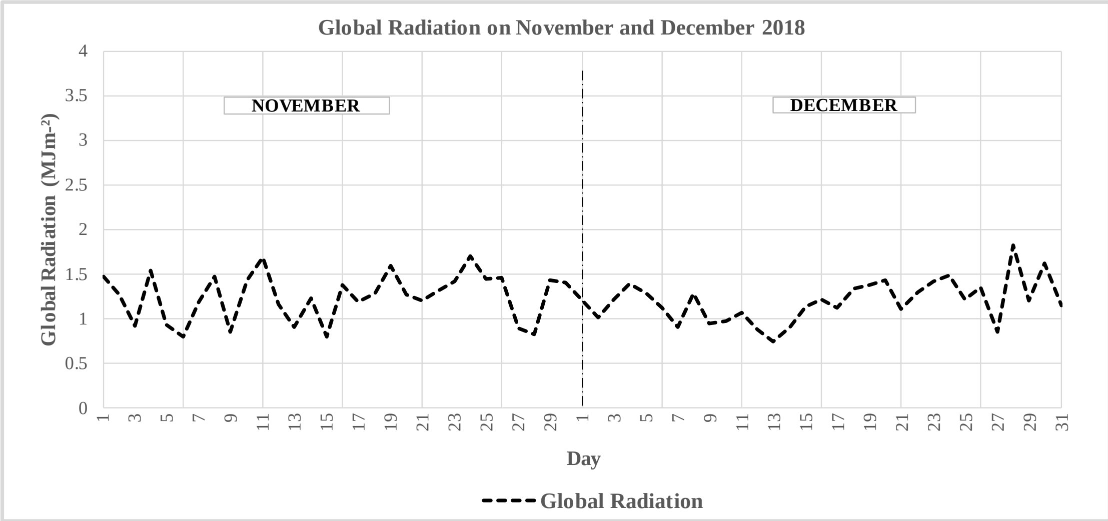


Figure 3 Global Radiation on November and December 2018

### 2.1 Measurement Procedure

The experiment was conducted without any occupants inside the classroom, and all the furniture remained in the classroom. The data for indoor thermal comfort parameter was collected using Thermal Microclimate Data Logger. The instrument was placed at the centre of the classroom (Figure 4) in order for the data to be collected which includes air temperature, air velocity, relative humidity and mean radiant temperature. According to Stazi (2017), the instrument located in the middle of the room represents sufficient indoor environmental parameters. All the sensor probes used to measure air temperature, air velocity, relative humidity and mean radiant temperature were installed at 1.4m from the floor. The probes of air velocity and Globe Thermometer were installed in parallel. Further, the probes were installed in a vertical position with 90° angle and free from any obstruction. According to Papazoglou *et al.* (2016), all the probes used to measure the thermal variables were placed in the sitting area of the occupants, where the method was supported by Mustapa *et al.* (2016) and Wang *et al.* (2017). The data for every parameter was logged for every 15 minutes, which were also applied by Nughoro (2007), Ismail (2010), Luo (2015) and Martin (2017) in their study. All the openings were opened, and all ceiling fans were switched off during the field experiment.

The data for an outdoor thermal parameter was collected using Velocicalc Air Velocity Meter. The data collected were air temperature, air velocity and relative humidity. The instrument was placed in an open space located outdoor. The probe was placed 1.2m from the ground in a vertical position with 90° angle without any obstruction. The data collected were logged every 15 minutes, concurrently with the indoor thermal parameter.

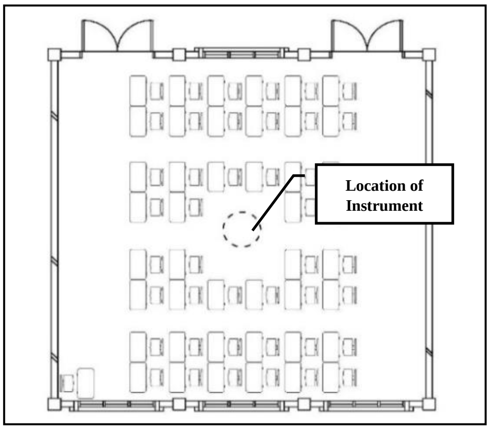


Figure 4 Location of Thermal Microclimate Datalogger

## 3 DATA ANALYSIS

All the data collected from the field experiment was analysed to evaluate the thermal performance of the classroom. Air temperature, relative humidity, air velocity, and mean radiant temperature were analysed to evaluate the indoor thermal performance of the classroom. At the same time, the outdoor thermal parameter, which includes air temperature, relative humidity and air velocity were analysed to determine the relationship between outdoor and indoor thermal parameter.

### 3.1 Data Analysis for Classroom A

Classroom A was oriented to South-East (Figure 1). There were a big tree and a building at the North-West which causes the obstruction to the classroom. Result gained from the field experiment which purposely to measure the indoor and outdoor thermal parameter was summarised in Table 1.

Table 1 Summary reading for an outdoor and indoor thermal parameter of Classroom A

| Parameter | Air Temperature (°C) | | Relative Humidity (%) | | Air Velocity (m/s) | | Mean Radiant Temperature (°C) |
|---|---|---|---|---|---|---|---|
| | Outdoor | Indoor | Outdoor | Indoor | Outdoor | Indoor | Indoor |
| Min. | 25.3 | 25.5 | 49.3 | 56.0 | 0.13 | 0.06 | 25.9 |
| Max. | 37.2 | 32.6 | 88.6 | 88.6 | 0.76 | 0.40 | 32.7 |
| Average | 34.1 | 30.0 | 59.1 | 67.2 | 0.52 | 0.21 | 30.2 |

Based on the graph in Figure 5, the air temperature for outdoor and indoor increased rapidly from 8.30am to 4.30pm. The average air temperature for outdoor was 34.1°C, while the average air temperature for indoor was 30.0°C (Table 1, Figure 5). There was no significant difference for outdoor and indoor air temperature at 8.30am. The outdoor air temperature slightly fluctuated from 12.30pm to 4.30pm. The relative humidity for outdoor and indoor decreased rapidly from 8.30am to 4.30pm (Figure 6). The average relative humidity for outdoor was 59.1%, while the average relative humidity for indoor was 67.2% (Table 1, Figure 6). At 8.30am, the reading of outdoor and indoor relative humidity was 88.6%, which shows a maximum reading. The outdoor relative humidity slightly fluctuated from 12.15pm to 3.00pm. Based on the plotted graph, the trend of air temperature and relative humidity shows a negative relationship within each other. When the air temperature increased, the relative humidity seems to decrease. The air velocity for both outdoor and indoor fluctuated during the experiment (Figure 7). The average air velocity of the outdoor was 0.52m/s, while the average air velocity of indoor was 0.21m/s (Table 1, Figure 7). The trend of graph plotted was similar between outdoor and indoor; however, the reading of outdoor air velocity was higher than the indoor air velocity. The mean radiant temperature was measured for indoor condition and purposely measured to determine the thermal comfort condition in a room. The mean radiant temperature was slightly higher than the indoor air temperature. Based on Figure 8, the mean radiant temperature increased rapidly from 8.30am to 4.30pm, and the average reading was 30.2°C. Result gained from the experiment showed that the indoor air temperature and air velocity was lower than the outdoor, while the indoor relative humidity was higher than the outdoor.

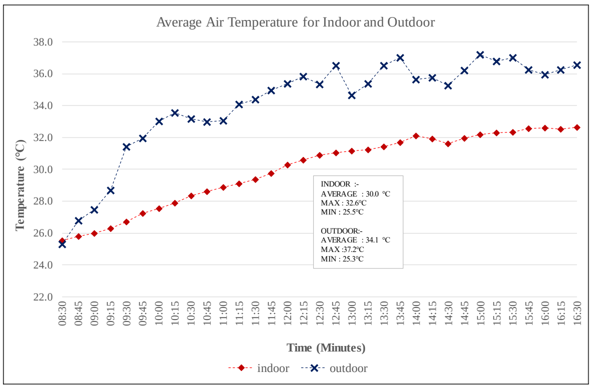


Figure 5 Average Air Temperature for Indoor and Outdoor

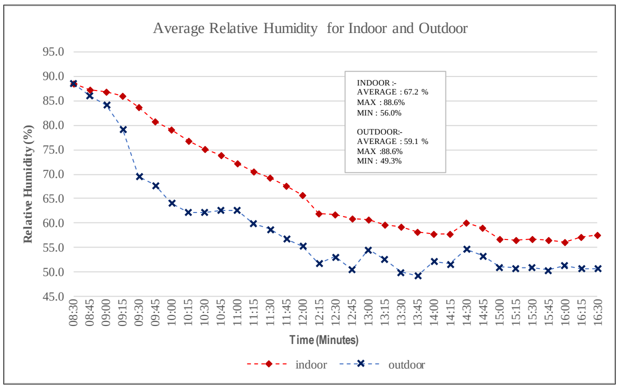


Figure 6 Average Relative Humidity for Indoor and Outdoor

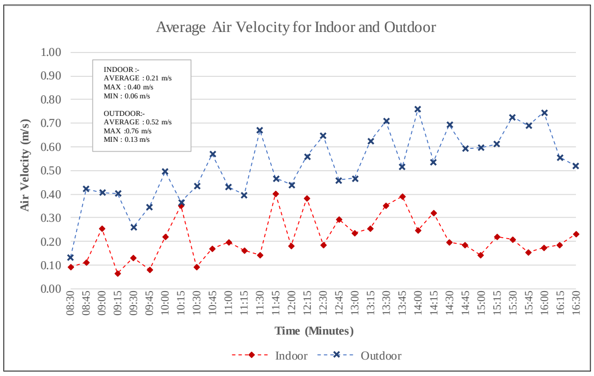


Figure 7 Average Air Velocity for Indoor and Outdoor

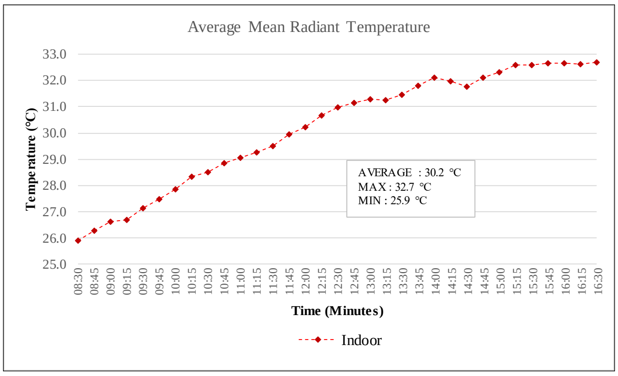


Figure 8 Average Mean Radiant Temperature for Indoor

Correlation analysis was conducted for air temperature, relative humidity and air velocity to measure the relationship between the indoor and outdoor parameter. According to Tong (2018), the Pearson correlation analysis is used to identify the behaviour of the variables. However, in this study, the Pearson correlation coefficient was used to determine the strength and direction of the linear relationship between outdoor and indoor parameter. The value of the correlation coefficient was measured between the range of-1 to +1. The larger the value of the coefficient (r) and the nearest the value to +1 or -1, it shows the stronger relationship between the parameter. Results gained from the experiment showed that the air temperature (Figure 9) and relative humidity (Figure 10) had a strong positive linear relationship between outdoor and indoor parameter with the r-value for air temperature was 0.91, and the r-value of relative humidity was 0.94. Based on Figure 11, the r-value for air velocity was 0.23, which indicates a weak positive linear relationship between outdoor and indoor parameter.

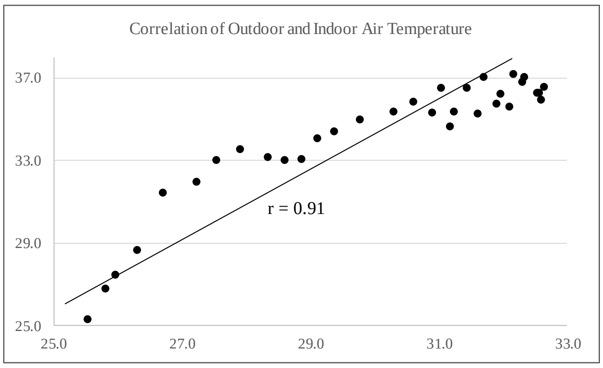


Figure 9 Correlation Outdoor and Indoor Air Temperature

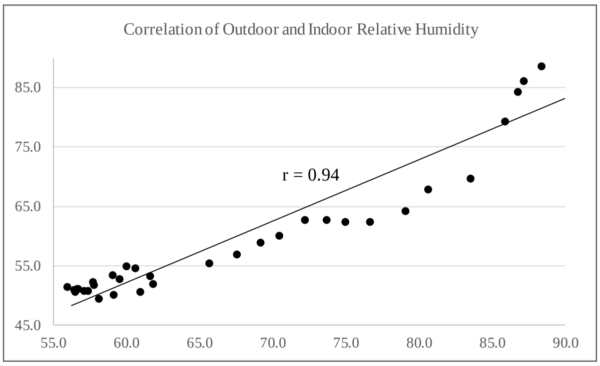


Figure 10 Correlation Outdoor and Indoor Relative Humidity

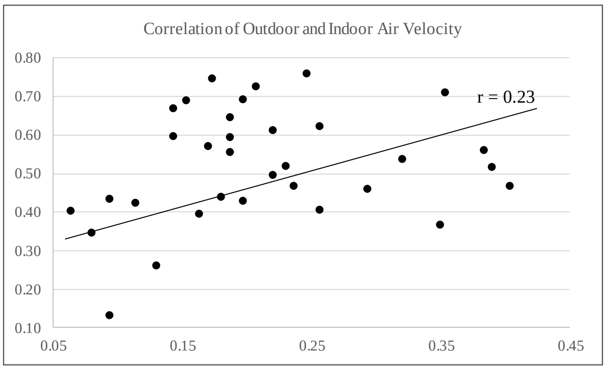


Figure 11 Correlation Outdoor and Indoor Air Velocity

### 3.2 Data Analysis for Classroom B

Classroom B was facing North-West orientation and obstructed by a building from South-East in U-shape. The results gained from the field experiment was summarised in Table 2.

Table 2 Summary reading for the outdoor and indoor thermal parameter of Classroom B

| **Parameter** | **Air Temperature (℃)** | | **Relative Humidity (%)** | | **Air Velocity (m/s)** | | **Mean Radiant Temperature (℃)** |
|---|---|---|---|---|---|---|---|
| | **Outdoor** | **Indoor** | **Outdoor** | **Indoor** | **Outdoor** | **Indoor** | **Indoor** |
| Min. | 25.4 | 26.5 | 48.7 | 59.1 | 0.19 | 0.08 | 27.1 |
| Max. | 36.8 | 31.4 | 87.8 | 84.5 | 0.83 | 0.82 | 31.0 |
| Average | 33.8 | 29.4 | 60.5 | 69.6 | 0.54 | 0.43 | 29.4 |

Based on Figure 12, the air temperature for indoor increased rapidly from 8.30am to 4.30pm. Whereas the outdoor air temperature increased from 8.30am to 11.15am, but slightly fluctuated from 11.45am to 4.30pm. The average air temperature for outdoor was 33.8°C, while average air temperature for indoor was 29.4°C (Table 2, Figure 12). The relative humidity for indoor decreased rapidly from 8.30am to 2.45pm and slightly increased from 3.00pm to 4.30pm. The outdoor relative humidity decreased rapidly from 8.30am to 12.30pm and slightly fluctuated from 2.45pm to 4.30pm. The average relative humidity for outdoor was 60.5%, while average relative humidity for indoor was 69.6% (Table 2, Figure 13). Based on the graph, the trend for both air temperature and relative humidity showed a negative relationship within each other, which the relative humidity decreased when the air temperature increased. The air velocity for outdoor and indoor fluctuated during the experiment (Figure 14). The average air velocity of the outdoor was 0.54m/s, while the average air velocity of indoor was 0.43m/s. The reading of indoor air velocity was captured higher than the outdoor between 12.00pm to 4.30pm. Based on the experiment for Classroom B, it was found that the indoor air temperature was lower than the outdoor, while the indoor relative humidity was higher than the outdoor. The mean radiant temperature increased rapidly from 8.30am to 12.30pm and slightly fluctuated from 12.45pm to 4.30pm (Figure 15).

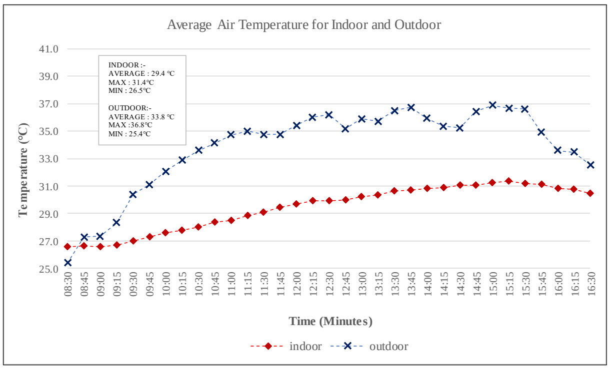


Figure 12 Average Air Temperature for Indoor and Outdoor

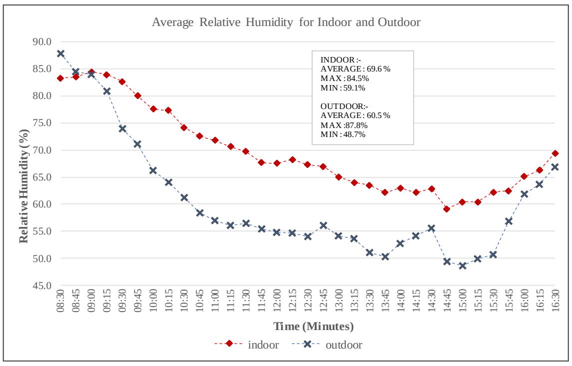


Figure 13 Average Relative Humidity for Indoor and Outdoor

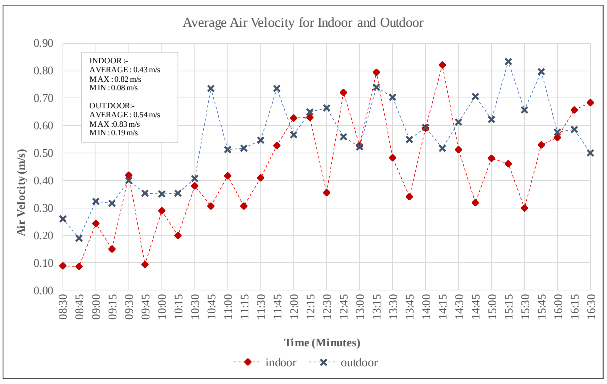


Figure 14 Average Air Velocity for Indoor and Outdoor

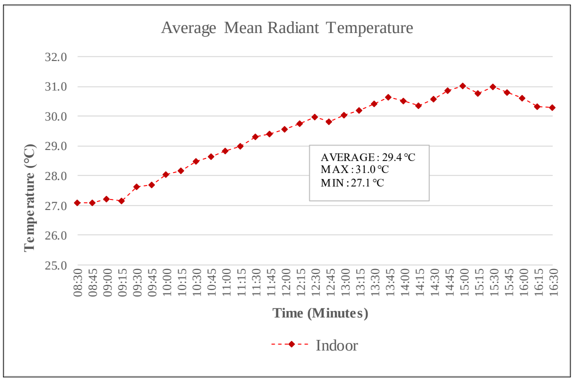


Figure 15 Average Mean Radiant Temperature for Indoor

Correlation analysis was also done for air temperature, relative humidity and air velocity to measure the relationship between indoor and outdoor parameter for Classroom B. Result gained from the experiment showed that the air temperature (Figure 16) and relative humidity (Figure 17) had a strong positive linear relationship between outdoor and indoor parameter with the r-value for air temperature was 0.84 and the r-value of relative humidity was 0.91. Based on Figure 18, the r-value for air velocity was 0.56, which indicates a moderate positive linear relationship between outdoor and indoor parameter.

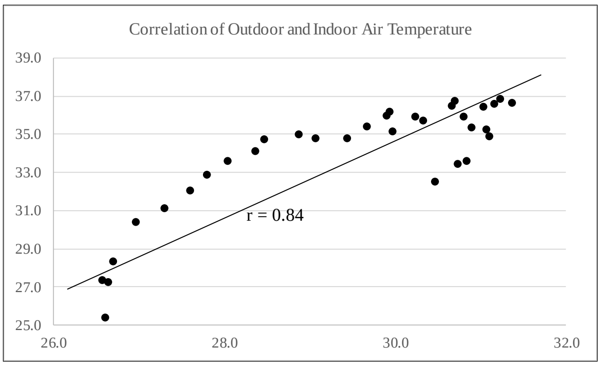


Figure 16 Correlation Outdoor and Indoor Air Temperature

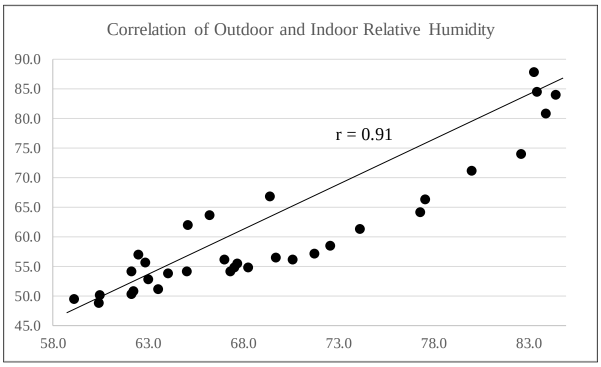


Figure 17 Correlation Outdoor and Indoor Relative Humidity

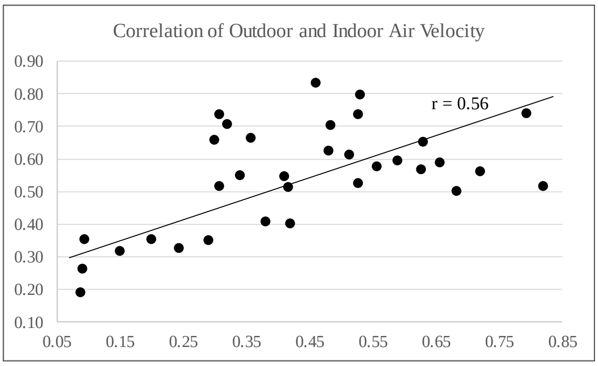


Figure 18 Correlation Outdoor and Indoor Air Velocity

### 3.3 Evaluation of Indoor Thermal Performance

According to Malaysian Standard MS1525:2014, the suitable range for air temperature in a classroom is between the range of 24°C - 26°C. The National Energy Efficiency Action Plan (NEEAP) 2014 issued by the Ministry of Energy, Science, Technology, Environment & Climate Change (MESTECC) which formerly known as KeTTHA had determined that 24°C is the suitable air temperature for an indoor environment. The results gained from the experiment showed that the average air temperature of Classroom A and Classroom B exceeded the standard requirement by MS1525:2014 and NEEAP 2014. The air temperature for both classrooms showed that there was a comfort condition in the morning with the reading of air temperature between 25°C – 26.5°C. However, the reading increased around 9.00am and continue to increase until 4.30pm which showed a discomfort condition in the classroom. The reading of mean radiant temperature for both classrooms also shows a discomfort condition. Correlation analysis for both classrooms shows a strong positive linear relationship between outdoor and indoor air temperature. The result indicates that the indoor air temperature had a significant influence by the outdoor air temperature. If the outdoor air temperature increases, the indoor air temperature will also increase because of the heat from outside the room that causes the increment of the air temperature. The suitable range of relative humidity required by MS1525:2014 in a classroom is between the range of 50% - 70%. From the experiment, the result shows that the average relative humidity of Classroom A and Classroom B have met the standard requirement made by MS1525:2014; however, the maximum reading has exceeded the standard requirement. This is due to the fact that the relative humidity has been influenced by the air temperature. When the air temperature inside the classroom increases, the relative humidity will decrease because of the heat that enters the room which also tend to reduce the content of moisture in the classroom. Based on the experiment, the comfort condition for both classrooms were found at the time frame between11.30am to 4.30pm. Correlation analysis of relative humidity for both classrooms indicate a strong positive linear relationship between outdoor and indoor reading, which clearly shows that the parameters were influenced by each other. The relative humidity of indoor will decrease as the outdoor reading decreases. According to Malaysian Standard MS1525:2014, the suitable range of air velocity in a classroom should be in between 0.15 m/s – 0.50 m/s. Based on the result from the experiment, the range of air velocity of Classroom A fulfilled the standard requirement set by MS1525:2014. The result showed that there was a comfort condition in the classroom at one particular time. Meanwhile, the reading of air velocity for Classroom B exceeded the standard requirement, which shows a discomfort condition in the classroom. Correlation analysis of air velocity for Classroom A shows a weak positive linear relationship, meanwhile for Classroom B it shows moderate positive linear relationship. However, both indoor and outdoor parameters had influenced each other for both classrooms.

## 4. DISCUSSION AND CONCLUSIONS

This study focuses more on the physical parameter of thermal comfort which are air temperature, mean radiant temperature, relative humidity and air velocity. The personal parameter of thermal comfort such as clothing, activity, age and gender are not included in this study as the field experiment was conducted without an occupant inside the classroom.

The results gained from the field experiment found that there was a discomfort condition in both classrooms based on the reading of air temperature, mean radiant temperature, relative humidity and air velocity. However, the reading of air velocity for Classroom A shows a comfort condition in the room. The outdoor parameter influenced all the indoor parameters for both classrooms. There was a small difference in the result for air velocity in Classroom A and B. This study found that there were influences from the orientation as well as outside obstruction which affect the result of the field experiment. Although Classroom A had met the standard requirement by MS1525:2014 for air velocity, there was a discomfort condition based on the value of air temperature and relative humidity. Classroom A which was oriented to South-East received much solar radiation in the morning from the East side of the room. The big tree and a building near to the classroom at the South causes an obstruction and prevent free wind movement into the room. Classroom B, which was facing North-West orientation, shows a discomfort condition in the classroom. Although the reading of air velocity was high inside the room, the reading of air temperature exceeded the standard requirement by MS1525:2014.

As conclusion, a naturally ventilated classroom shows a discomfort condition inside the room as the thermal performance of the classroom was very much influenced by the orientation and also outside obstruction of the classroom. Furthermore, this study also found that the outdoor thermal parameter has influenced all the indoor thermal parameters in a tropical climate. As a suggestion for future improvement, the orientation and the design of the opening should be improvised further especially in a government educational institution which play a vital role in the process of teaching and learning.

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