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Evaluating Ventilation for Thermal Comfort in Two Classrooms Types in Malaysian Secondary Classrooms

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ABSTRACT

This study aimed at evaluating the ventilation quality in two secondary school buildings in Malaysia with two different layouts, representing one single- and one double-loaded-corridor design model. One classroom was chosen from each school for the study. In this study, the method uses computer simulations and user surveys to compare results on designing future secondary schools in Malaysia. DesignBuilder software were used to simulate the exterior and interior airflow, temperature, and humidity for various times of the year, with data collected from the simulations were fed into and analyses through the online CBE Thermal Comfort Tool to determine thermal comfort performance by using adaptive approach method. The simulations were performed for the same locations, on the same dates, and under the same environmental conditions to obtain comparable results. The simulation data were used to split the classrooms into thermal zones, with the thermal comfort rate for each zone being determined on the specified dates. A user survey to determine satisfaction levels and obtain comments was conducted with 67 participants (all students plus three teachers from each classroom). It was found that the single-loaded-corridor system provided greater thermal comfort throughout the year due to reduced temperatures and enhanced airflow.

1. INTRODUCTION

This study aims to contribute to examining the ventilation quality of secondary school buildings in Malaysia, specifically comparing the ventilation between the single-loaded and double-loaded corridors. Additionally, this study seeks to compare the thermal comfort level between the two designs, as improving thermal comfort has been shown to enhance student comfort and concentration. By addressing these research objectives, this study can offer insights into how school design can be optimized to promote better student learning outcomes.

The outdoor temperatures in Malaysia are mostly constant throughout the day, ranging between 23.7 and 31.3℃, on average, while the weather is tropical--that is, mostly humid and hot. This type of climate clearly has the potential to affect the comfort of people in the indoor environment deleteriously. Ahmad et al. [1] analysed the effects of different constructions on the thermal comfort of Malaysian school classrooms, finding that the classroom interiors ranged in temperature between 28 and 34.5℃, which is higher than the recommended temperature for thermal comfort in a tropical climate. The authors also showed that the air movement in the classrooms was unsatisfactory, and producing unacceptable levels of noise. Therefore, appropriate layouts and ventilation need to be considered when designing buildings so as to increase natural ventilation and thermal comfort while reducing the need for air-conditioning.

School buildings fall into the category of important buildings in which the indoor conditions can affect the occupants' performance, health and learning [2]. Among the various aspects that contribute to learning efficiency, the learning environment stands out and deserves the most consideration because it has a direct influence on student achievement [3]. For example, the layout of a school can have a significant impact on the thermal comfort and ventilation of the interior [4]. Previous field studies have demonstrated conclusively that increased temperatures can reduce schoolchildren's productivity, with their academic achievement being mostly affected by discomfort in the learning environment, decreasing when temperature and humidity surpass their comfort levels [5-7]. According to Stadler-Altmann [8], regardless of the fact that humans are highly adaptable, students cannot perform effectively in an uncomfortable setting. Also, Hwang et al. [9] stated that when children experience discomfort from high temperatures, their academic performance can plummet by as much as 24%. Because children are less resistant to negative environmental variables than adults, more effort must be made to make school classrooms thermally comfortable. Providing a comfortable and healthy microclimate is especially essential for educational buildings because environmental quality can considerably improve the occupants' learning performance [10, 11].

The provision of thermal comfort in classrooms is also a necessity because students spend up to one-third of the day in school [12]. Elevated air temperatures are the most ubiquitous problem, worsened when ventilation rates are too low to expel heat properly, such as in cases where teachers or school authorities keep the windows closed to avoid disruptions caused by external noise and the discomfort created by air pollution. Although there is a well-established relationship

between student achievement and indoor environmental conditions, in general, the effect of school design on thermal comfort under naturally ventilated conditions is still not very well understood, specifically in the context of secondary school classrooms in Malaysia [13]. Recently, several field studies, based on the adaptive thermal approach, have been conducted in various countries and climatic areas [14-16], buildings [17-19], and types of space conditioning, including natural, hybrid or mixed-mode buildings [20]. While studies have been conducted on the effects of classrooms on student learning outcomes [13], there is still a gap in understanding how space impacts learning. As such, it is important to investigate how classroom design can affect learning environment.

2. MATERIALS AND METHODS

A variety of research methods were employed to address the research questions in this study. Specifically, simulation and survey methods were used to compare results for designing secondary schools in one single- and one double-loaded-corridor design model in Malaysia. To collect data, the researchers used DesignBuilder software to simulate exterior and interior airflow, temperature, and humidity for various times of the year. The data collected from the simulations were then analyzed using the online CBE Thermal Comfort Tool to determine the thermal comfort performance based on adaptive approach to thermal comfort. The simulations were conducted for the same locations, on the same dates, and under the same environmental conditions to ensure comparable results. The entire research process is depicted in Figure 1.

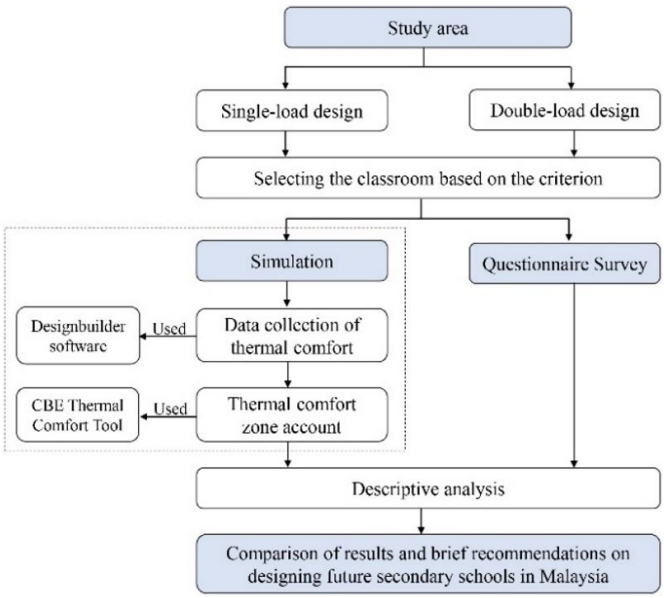

Figure 1. The research process

2.1 Study area

Historically, school designs in Malaysia have followed the Public Works Department and Economic Planning Unit guidelines, in terms of layout design and materials selection. The case studies selected to represent two different school designs in Malaysia were the Sekolah Menengah Kebangsaan (SMK) Seri Serdang (single-loaded corridor) (Figure 2), and the SMK Taman Desaminium (double-loaded corridor) (Figure 3), both examples of designs recently used by the Public Works Department for new schools.

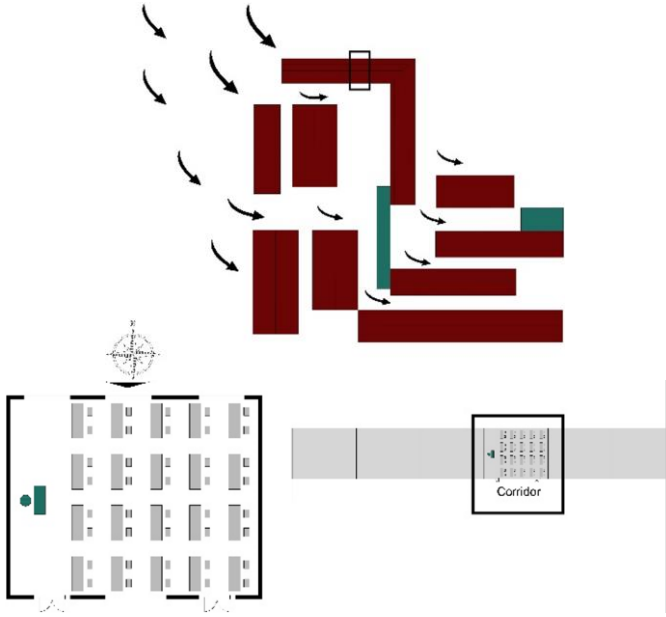

Figure 2. SMK Seri Serdang (single-load design)

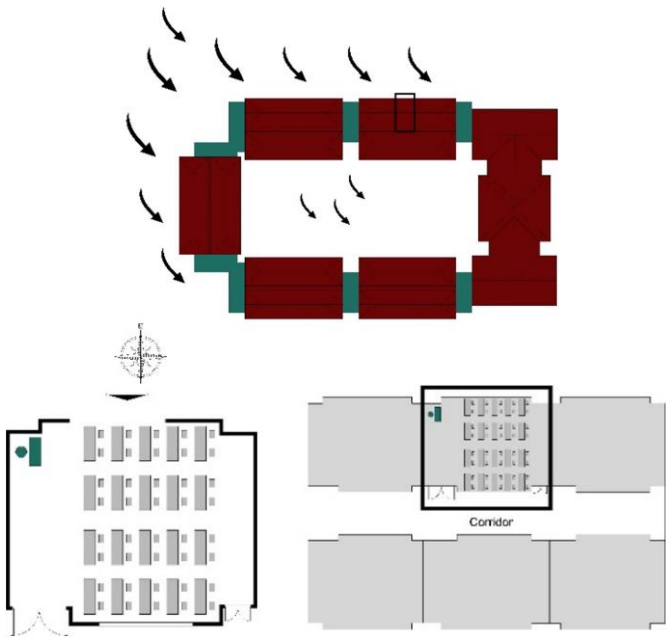

Figure 3. SMK Taman Desaminium (double-load design)

The SMK Seri Serdang is located in Seri Kembangan, Selangor, in a flat, low-rise urban area. The school originally had two buildings, but with additional blocks added later. Its single-loaded-corridor design features a corridor on one side of the classroom. The classrooms are oriented in linear east-west blocks, which enhance wind movement between the blocks. The classrooms have natural ventilation from four large windows (three on the exterior wall and one looking onto the corridor) to create a cross-ventilation system that cools the entire space.

The SMK Taman Desaminium is located in Seri Kembangan, Selangor, on slightly sloping land in an open rural area surrounded by trees. The school hosts primary- and secondary-level students, with nine blocks for each. The corridor divides two rows of classrooms, which feature a

courtyard configuration that limits the flow of wind between the blocks. The cross-ventilation system in these classrooms comprises one large window, divided into six vertical sections with multiple horizontal panes of glass, on the outer wall and one long and narrow window looking onto the corridor.

Both schools have three floors. A classroom on the second floor was selected from each, where the effects of solar radiation and the heat energy absorbed by the bricks and concrete were less pronounced compared to the heat energy transmitted to the top floor by direct solar radiation. The same was true for choosing the location of the case-study classrooms, with the external walls able to absorb high thermal energy from their partial exposure to direct sunlight. Thus, the classrooms were chosen from the middle of a block of rooms and were situated on the north side of the school, facing the wind and getting the best ventilation.

2.2 Simulation

A computer simulation uses software to build a model with conditions that mimic a real-life situation in order to experiment or explore the behaviour of the model under specific conditions that are not possible to achieve in real life. Here, DesignBuilder software (https://designbuilder.co.uk/) was used to create the simulation because it provided the easiest workflow coupled with the latest approved calculations and building regulations compliance checks for Malaysia. DesignBuilder was designed to create different types of simulations, such as lighting, heat, comfort, cost and energy. Two dates were selected for the simulations, representing months in which the highest and lowest temperatures and wind speeds of the year occurred--15 May, 2021 (lowest temperature and highest wind speed) and 15 September, 2021 (highest temperature and lowest wind speed). On the 15th of the month, the average space humidity, wind speed, operative temperature and outdoor temperature were measured every 5 min for 12 h in order to provide the most accurate data. The following assumptions were used in the simulations for each school: 1) the models were oriented east-west because this was the most appropriate for the climate; 2) the same wind conditions applied to both models; 3) all of the windows were open at the same level; 4) natural ventilation contributed to the overall operative temperature of the classrooms; and 5) thermal comfort was achieved through natural ventilation facilitated by the open windows.

The data extracted from the simulations were these environmental variables: humidity, indoor air temperature, radiant air temperature, operating temperature, outdoor air temperature and wind speed. These data were extracted at a rate of every 5 min of 5 h per day, distributed as follows: 7:00-8:00 am, 10:00-11:00 am, 1:00-2:00 pm, 4:00-5.00 pm and 7:00-8:00 pm. The data were averaged for each hour and plotted on a chart (see Appendices A and B).

The thermal comfort module included air velocity and humidity for calculating the operative temperature. The data collected from the simulations were fed into and analysed through the online CBE Thermal Comfort Tool (https://comfort.cbe.berkeley.edu/) in order to determine the thermal comfort performance.

2.3 Questionnaire survey

A survey was employed to determine the success of each classroom plan in achieving natural ventilation by assessing the users' perceptions. The survey contained two sections with 12 categories in total. Section A was about the users' demographic background and included four categories--name, school grade, gender, and age. Section B involved the level of thermal comfort in the classroom and included eight categories aimed at understanding the perceptions and comfort of the students in terms of temperature at different times of the day as well as their satisfaction with the airflow and the elements available for controlling the temperature and airflow in the classroom (windows, air- conditioning, adjustable air vents, ceiling fans, portable fans, and window shades or blinds). To measure the satisfaction with temperature and airflow, a seven-point thermal sensation scale (hot, warm, slightly warm, neutral, slightly cool, cool, cold) was used. The survey was devised from Shaari and Ahmad [3] and modified to simplify the questions for the secondary school students. Permission for access to the students to conduct the surveys was sought from the Selangor Ministry of Education, but the management bodies in both schools would not allow us direct access to the students. Therefore, the questionnaires were handed to the management bodies on 13 April, 2021 and then personally collected on 15 April, 2021.

The students were surveyed from one classroom in each school. There was a total of 67 respondents--30 students and three teachers from the SMK Seri Serdang and 31 students and three teachers from the SMK Taman Desaminium.

3. RESULTS

3.1 Evaluation of the thermal comfort by simulation

The main aim of the simulations was to evaluate the thermal comfort based on the different layouts and ventilation designs in two different schools. The variables determined were humidity, indoor air temperature, radiant air temperature, operating temperature, outdoor air temperature and wind speed, and the data were gathered every 5 min for 5 h per day (Appendices A and B).

The data for the SMK Seri Serdang on 15 May, 2021 revealed that the average relative humidity in the classroom was 77.93%, the indoor air temperature was 28.27℃, the radiant air temperature was 29.13℃, the operative temperature was 28.60℃, the outdoor temperature was 25.27℃, and the average wind speed was 0.6 Mps (see Table 1). For the same day, for the SMK Taman Desaminium, the average relative humidity in the classroom was 82.56%, the indoor air temperature was 29.02℃, the radiant air temperature was 28.62℃, the operative temperature was 28.82℃, the outdoor temperature was 25.28℃, and the average wind speed was 0.6 Mps (see Table 2).

The data for the SMK Seri Serdang on 15 September, 2021 revealed an average relative humidity in the classroom of 63.16%, the indoor air temperature was 31.28℃, the radiant air temperature was 31.68℃, the operative temperature was 31.41℃, the outdoor temperature was 27.60℃, and the average wind speed was 0.6 Mps (see Table 3). For the same day, the data for the SMK Taman Desaminium included an average relative humidity in the classroom of 73.55%, the indoor air temperature was 31.19℃, the radiant air temperature was 30.78℃, the operative temperature was 30.99℃, the outdoor temperature was 27.60℃, and the average wind speed was 0.6 Mps (see Table 4).

Table 1. Simulated measurements taken on 15 May, 2021 in the SMK Seri Serdang classroom

Average Time 15/05/2021	Humidity %	Indoor Air T. ℃	Radiant Air T. ℃	Operative T. ℃	Outdoor Air T. ℃	Wind Speed Mps
7:00-8:00 am	72.90	29.28	29.50	29.39	25.60	0.60
10:0-11:0 am	74.90	29.93	29.21	29.06	24.90	0.60
1:00-2:00 pm	76.04	28.64	28.90	28.76	24.78	0.60
4:00-5:00 pm	85.42	26.58	28.75	27.67	25.15	0.60
7:00-8:00 pm	80.41	26.94	29.29	28.12	25.92	0.60
Average day	77.93	28.27	29.13	28.60	25.27	0.60

T.=Temperature

Table 2. Simulated measurements taken on 15 May, 2021 in the SMK Taman Desaminium classroom

Average Time 15/05/2021	Humidity %	Indoor Air T. ℃	Radiant Air T. ℃	Operative T. ℃	Outdoor Air T. ℃	Wind Speed Mps
7:00-8:00 am	80.11	28.82	28.90	28.89	25.75	0.60
10:0-11:0 am	80.19	28.46	28.61	28.53	24.90	0.60
1:00-2:00 pm	80.45	28.09	28.25	28.17	24.75	0.60
4:00-5:00 pm	87.64	29.76	28.47	29.11	25.12	0.60
7:00-8:00 pm	84.44	29.98	28.91	29.44	25.92	0.60
Average day	82.56	29.02	28.62	28.82	25.28	0.60

T.=Temperature

Table 3. Simulated measurements taken on 15 September, 2021 in the SMK Seri Serdang classroom

Average Time 15/09/2021	Humidity %	Indoor Air T. ℃	Radiant Air T. ℃	Operative T. ℃	Outdoor Air T. ℃	Wind Speed Mps
7:00-8:00 am	60.09	31.49	32.26	31.87	26.80	0.30
10:0-11:0 am	60.61	31.27	31.74	31.12	25.71	0.30
1:00-2:00 pm	63.75	30.73	31.20	30.96	25.17	0.30
4:00-5:00 pm	70.96	29.89	31.00	30.47	28.01	0.30
7:00-8:00 pm	60.43	33.04	32.21	32.63	32.35	0.30
Average day	63.16	31.28	31.68	31.41	27.60	0.30

T.=Temperature

Table 4. Simulated measurements taken on 15 May, 2021 in the SMK Taman Desaminium classroom

Average Time 15/09/2021	Humidity %	Indoor Air T. ℃	Radiant Air T. ℃	Operative T. ℃	Outdoor Air T. ℃	Wind Speed Mps
7:00-8:00 am	67.03	30.93	31.32	31.13	26.80	0.30
10:0-11:0 am	67.49	30.62	30.84	30.73	25.71	0.30
1:00-2:00 pm	68.61	30.09	30.34	30.22	25.17	0.30
4:00-5:00 pm	81.54	31.59	30.42	31.00	28.01	0.30
7:00-8:00 pm	83.08	32.72	31.01	31.87	32.35	0.30
Average day	73.55	31.19	30.78	30.99	27.60	0.30

T.=Temperature

3.2 Evaluation of thermal comfort zones using the online tool

Thermal comfort plots and calculations were created using the online CBE Thermal Comfort Tool and the average operative temperature, average mean outdoor temperature and average wind speed for each hour. A comparison of the data from the two schools showed that the single-loaded-corridor design provided a better thermal comfort level than the double-loaded-corridor design in May (lowest temperature, highest wind speed), with a comfort zone of 100% in the single-loaded-corridor classroom compared 80% in the double-loaded-corridor design. In September (highest temperature, lowest wind speed), it was noted that both classrooms were 100% outside the comfort zone (see Table 5).

In May, the thermal environment in the classroom of the SMK Seri Serdang was considered to be comfortable because it fell within the 90% comfort zone. From 7:00 to 11:00 am, the thermal level was just within the 90% comfort zone and as the day progressed, it moved towards the middle of the 90% comfort zone. So, the SMK Seri Serdang classroom was within the 90% thermal comfort zone all day. In the SMK Taman Desaminium classroom, from 7:00 am until 3:00 pm, the thermal environment inside the classroom was considered comfortable, sitting within the 80% comfort zone. However, the environment moved slightly outside this thermal zone between 4:00 and 5:00 pm, moving back, and into the 90% comfort zone, at 7:00 pm.

In September, the thermal comfort level in the SMK Seri Serdang classroom between 7:00 am and 8:00 pm was too warm, with the thermal level falling outside the comfort zone, although the interior environment was the closest to the 80% comfort zone between 4 and 5 pm. Likewise, the thermal level in the SMK Taman Desaminium classroom between 7:00 am and 8:00 pm was outside the comfort zone. From the analysis, on 15 September, 2021, both classrooms were outside the thermal comfort zone 100% of the day.

Figure 4 shows the thermal comfort level in both classrooms for May and September. The location of each dot represents an hour of the day between 7:00 am and 08:00 pm.

Table 5. Comparison between the thermal comfort ratios of the two different classrooms

Thermal Comfort Ratio	SMK SS Single-Loading Design		SMK TD Double-Loading Design	
	May	September	May	September
90%	100% (12 hours)	-	20% (2 hours)	-
80%	-	-	60% (8 hours)	-
Outside comfort zone	-	100% (12 hours)	20% (2 hours)	100% (12 hours)

SMK SS=SMK Seri Serdang
SMK TD=SMK Taman Desaminium

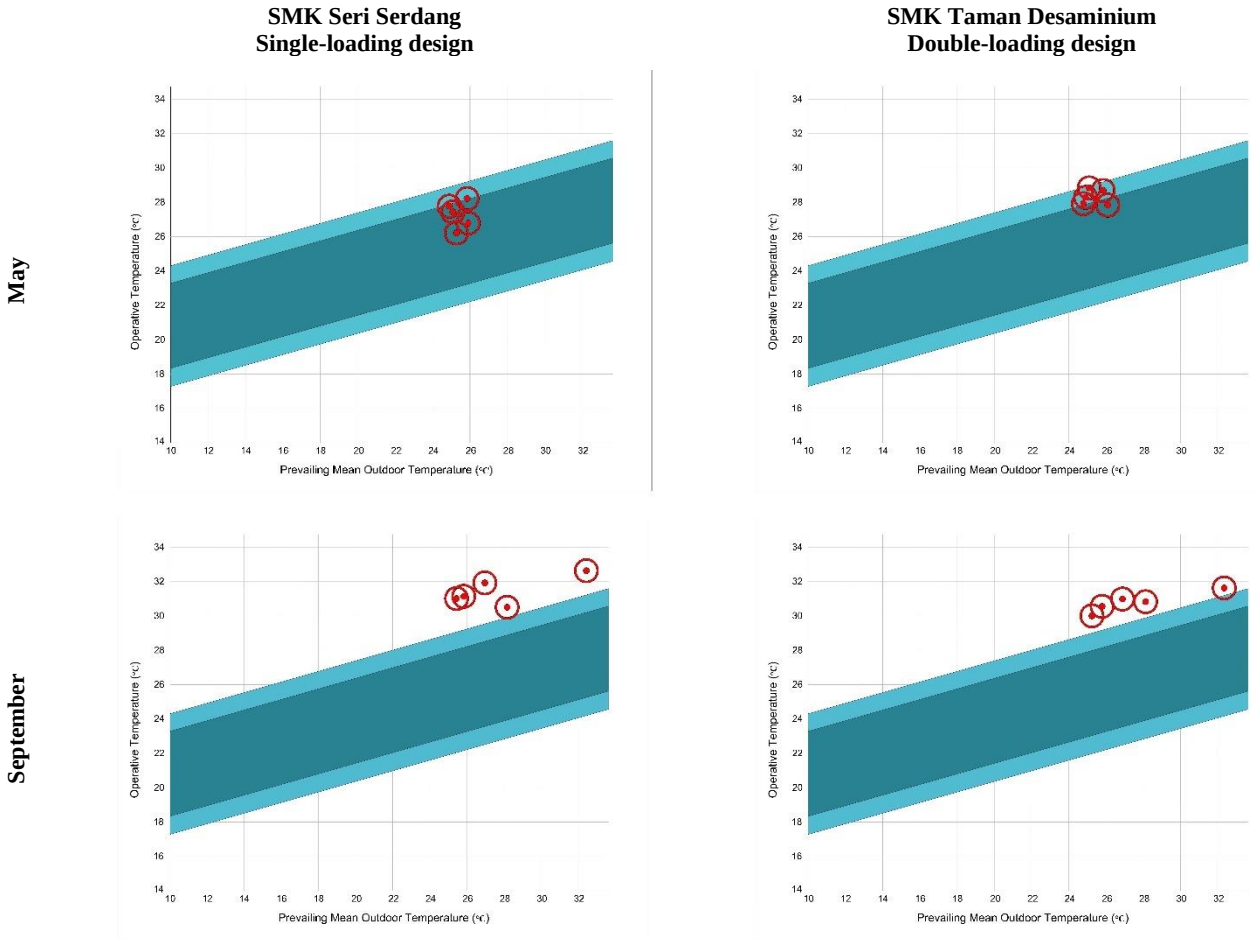

Figure 4. Thermal comfort levels in the classrooms

3.3 Occupants survey of the thermal comfort levels

The main aim of the survey was to understand student comfort levels in the classrooms and to be able to make comparisons. The respondents were taken from one classroom in each school.

Table 6. Demographics of the survey participants

Categories	Demographic	SMK SS F.	SMK TD F.
Grade	Eleventh	30	31
Gender	Girls	16	16
	Boys	14	15
	Teachers	3	3
Age	16 years (students)	30	31
	30 to 50 years (teachers)	3	3

SMK SS=SMK Seri Serdang
SMK TD=SMK Taman Desaminium
F.=Frequency

A total of 67 respondents were surveyed made as 61 students and 6 teachers. From the survey, it was found that all the students were of the same age (16 years old) and in the same grade (11th). The teachers ranged in age between 30 and 50 years. In terms of gender, the SMK Seri Serdang class contained 16 girls and 14 boys, whereas the SMK Taman Desaminium class contained 16 girls and 15 boys (Table 6).

From Table 7, which shows how the students gauged the temperature in the classroom at different times of the day, it can be seen that most respondents (32.4%) in the single-loaded-corridor layout found the classroom to be cool in the morning, while 42.4% of the respondents in the double-loaded-corridor layout found it warm. At noon, most of the respondents chose between neutral (26.5%) and slightly cool (23.5%) for the single-loaded-corridor layout. For the double-loaded-corridor layout, more than half of the respondents (57.6%) found the classroom to be hot, mostly in the afternoon (78.7%) and evening (63.6%) compared to the single-loaded-corridor layout, which was slightly cool in the afternoon (32.2%) and slightly warm in the evening (32.4%).

Table 7. Student comfort with the temperature in the classroom at different times of the day

Question	School	Category						
		Hot	Warm	Slightly Warm	Neutral	Slightly Cool	Cool	Cold
How do you feel about the temperature in the classroom in the morning?	SMK-SS	0.0%	5.9%	5.9%	11.8%	26.4%	32.4%	17.6%
	SMK-TD	18.2%	42.4%	12.1%	18.2%	0.0%	9.1%	0.0%
How do you feel about the temperature in the classroom at noon?	SMK-SS	5.9%	17.6%	11.8%	26.5%	23.5%	14.7%	0.0%
	SMK-TD	57.6%	21.1%	6.1%	6.1%	9.1%	0.0%	0.0%
How do you feel about the temperature in the classroom in the afternoon?	SMK-SS	14.7%	11.8%	17.8%	11.8%	32.2%	8.8%	2.9%
	SMK-TD	78.7%	6.1%	9.1%	6.1%	0.0%	0.0%	0.0%
How do you feel about the temperature in the classroom in the evening?	SMK-SS	5.9%	8.8%	32.4%	29.4%	17.6%	5.9%	0.0%
	SMK-TD	63.6%	15.2%	18.2%	3.0%	0.0%	0.0%	0.0%
In the 12 months a year, how satisfied are you with the temperature in your classroom?	SMK-SS	5.9%	11.8%	14.7%	47.0%	8.8%	11.8%	0.0%
	SMK-TD	75.8%	12.1%	3.0%	9.1%	0.0%	0.0%	0.0%
How satisfied are you with the temperature in your classroom today?	SMK-SS	5.9%	2.9%	8.8%	50.1%	17.6%	11.8%	2.9%
	SMK-TD	69.7%	6.1%	15.1%	6.1%	3.0%	0.0%	0.0%
How do you feel about the airflow in the classroom at this moment?	SMK-SS	0.0%	5.9%	14.7%	44.1%	23.5%	11.8%	0.0%
	SMK-TD	72.7%	12.1%	9.1%	6.1%	0.0%	0.0%	0.0%

SMK-SS=SMK Seri Serdang
SMK-TD=SMK Taman Desaminium

Most of the respondents from the single-loaded-corridor classroom rated their satisfaction with the overall yearly temperature as neutral (47.0%), while 75.8% of the respondents from the double-loaded-corridor classroom found it hot. The same goes for their satisfaction with the temperature on the day of the survey at 12 pm, with the respondents from the single-loaded-corridor classroom finding it neutral (50.1%) and 69.7% from the double-loaded-corridor classroom finding it hot. When asked how they felt about the airflow in the classroom at that time, 44.1% of the single-loaded-corridor respondents reported it as neutral, whereas 72.7% in the double-loaded-corridor room found it hot.

In terms of adjusting or controlling the classroom environment, most respondents (82.4%) in the single-loaded-corridor layout used windows to adjust the temperature, whereas most of those in the double-loaded-corridor classroom used ceiling fans (75.8%).

Analysis of the survey responses showed higher satisfaction rates in the single-loaded-corridor classroom due to lower temperatures year round and the enhanced air speed and movement. In summary, most respondents from the single-loaded-corridor classroom found it to be neutral to slightly cool during the day, and most respondents from the double-loaded-corridor classroom considered it to be warm in the morning and hot for the rest of the day. This led to them relying more on windows for cooling in the single-loaded-corridor classroom and on ceiling fans in the double-loaded-corridor classroom to improve their thermal comfort.

4. DISCUSSION

We assessed two features of school design in Malaysia that had an impact on natural ventilation--the single- and double-loaded corridor. The former was represented by the SMK Seri Serdang school and the latter by the SMK Taman Desaminium school. We used objective data analysis to describe the environmental conditions of the two classrooms, coupled with a subjective analysis via questionnaire to record and evaluate the thermal sensations felt by the students. Comparisons were made through computer simulation analysis and a thermal comfort analysis was performed by plotting the internal classroom conditions on adaptive thermal comfort charts. Thus, we put forward a concept for implementing virtual reality environments to address design challenges, rather than relying on building designer intuition. Our results were found to be consistent with those of Al-sharaa et al. [21].

The linear design of the SMK Seri Serdang allowed for better wind flow between the blocks compared with the courtyard design of the SMK Taman Desaminium. The enhanced air movement between the school blocks led to overall better ventilation and interior air quality. There were more windows in the SMK Seri Serdang. This difference in layout and windows promoted better wind flow and ventilation in the SMK Seri Serdang than in the SMK Taman Desaminium.

From the simulations and survey, we discovered that the single-loaded-corridor design offered overall greater thermal comfort in May. In comparing the simulations, the single-loaded-corridor classroom resulted in 100% of the day being in the comfort zone in May, compared with 60% of the day within the 80% comfort zone and 20% of the day within the 90% comfort zone for the double-loaded-corridor classroom design in May. However, both classroom designs were completely outside the thermal comfort zone 100% of the day in September. To overcome this, ceiling fans were used to increase the air speed in the classrooms, which achieved a better thermal comfort experience. This shows that, even though using a single-loaded-corridor design to improve the thermal comfort level in the classroom, this is not enough to achieve year-round thermal comfort in Malaysian weather. The lack of thermal comfort in the hotter months implies the lack of a comfortable temperature, deleterious effects on the occupants' health and higher energy consumption [22]. These findings were supported by the user's preferences, which showed a higher rate of satisfaction in the single-loaded-corridor classroom. The low comfort rate in the double-loaded-corridor design has potentially led to decreased student performance and motivation, based on studies that have found that, regardless of the fact that the human organism is very adaptive, students cannot perform well when their environment is uncomfortable [8, 23].

Future Malaysian schools are recommended to be built to the single-loaded-corridor design, as used for the SMK Seri Serdang Secondary School. This would provide improved air circulation and overall natural ventilation. However, other methods of cooling might still be needed during the hotter months, such as ceiling fans. A school's layout must also take into consideration enhanced wind movement between the

school blocks, which also leads to better interior ventilation. Windows in classrooms should be maximised in size and be placed on both the exterior wall and the corridor wall, allowing for enhancing air circulation and lowering the interior temperature. Improving the ventilation and thermal comfort levels in future classrooms would lead to higher student performance, which could improve the level of Malaysian education.

5. CONCLUSIONS

The main conclusions of this study include focusing on designing future classrooms in single-loaded corridor layouts and improving natural ventilation for higher thermal comfort in Malaysian schools. The results found single- versus double-loaded corridor layouts in schools have different effects on the thermal comfort of students. In terms of natural ventilation, the single-loaded corridor classroom had faster and stronger air movement and better air circulation than the double-loaded corridor classroom. The single-loaded corridor design had an overall lower temperature than the double-loaded corridor design when used in the same environment. It was also noted, from the wind simulation, that the linear design enhanced wind movement between the blocks more than in the courtyard. In terms of thermal comfort rates, we found that the single-loaded corridor design offered a higher thermal comfort rate than the double-loaded corridor design. This was also supported by the user survey, which showed overall higher satisfaction with the single-loaded corridor design. Because this study only focused on classroom ventilation by briefly covering the school layout and design, future studies can cover other school spaces, such as facilities and courtyards, in order to enhance student comfort across the entire school. Overall, this study has contributed to the knowledge base in the field of sustainable architecture concerning the development and enhancement of the thermal conditions of secondary school classrooms for producing better educational environments.

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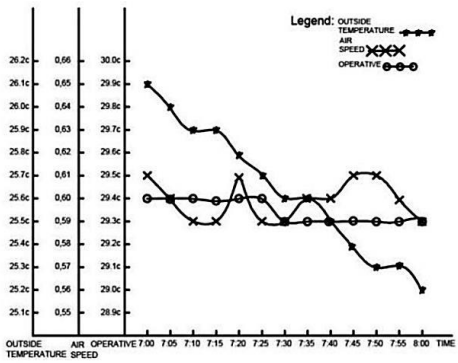
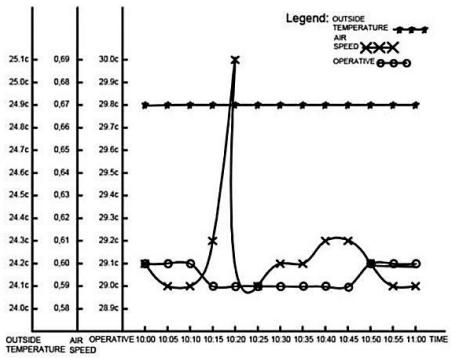
APPENDIX

Appendix A. Measurement thermal comfort of classroom on 15/May/2021

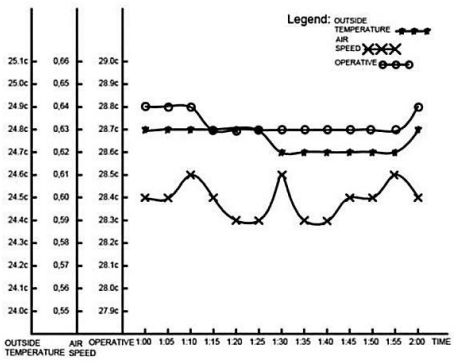
SMK Seri Serdang classroom



15/May/2021, time 7:00-8:00 am

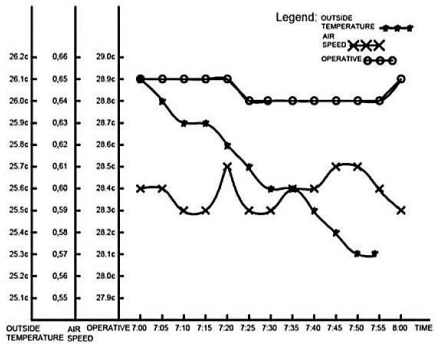


15/May/2021, time 10:00-11:00 am

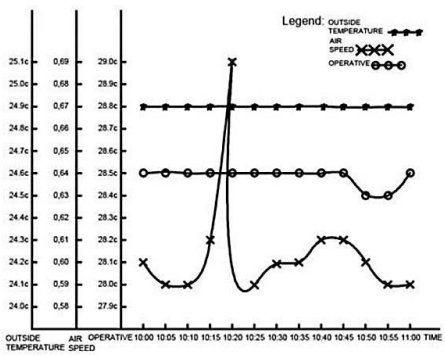


15/May/2021, time 1:00-2:00 pm

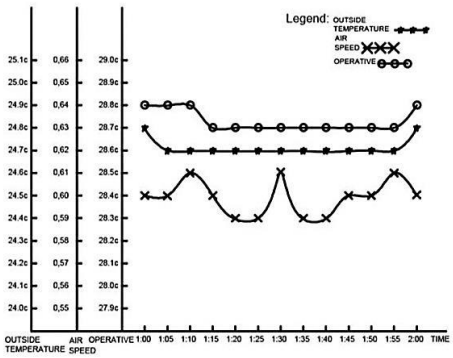
SMK Taman Desaminium classroom



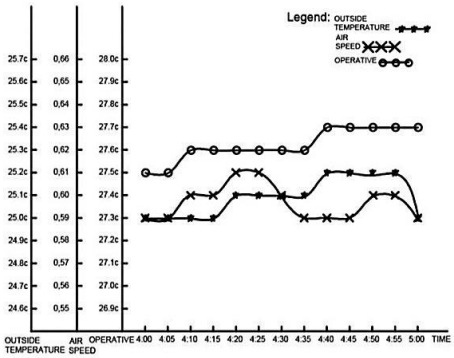
15/May/2021, time 7:00-8:00 am



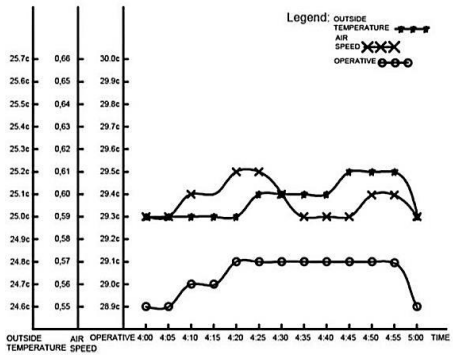
15/May/2021, time 10:00-11:00 am



15/May/2021, time 1:00-2:00 pm



15/May/2021, time 4:00-5:00 pm



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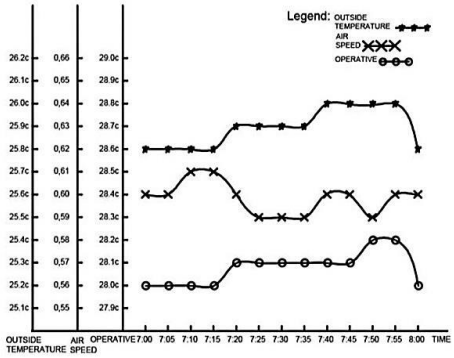
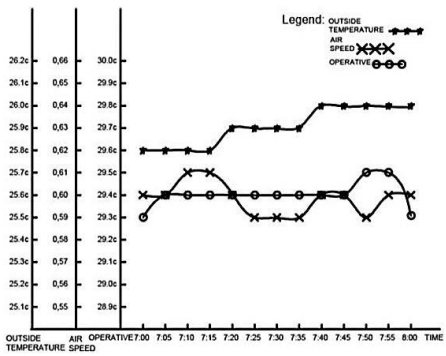


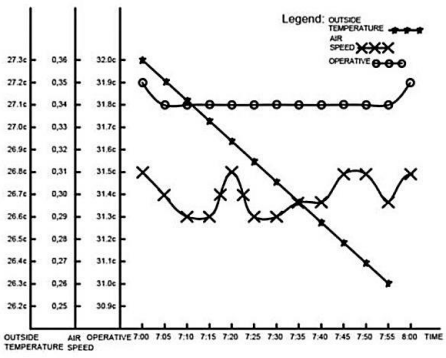
15/May/2021, time 7:00-8:00 pm



15/May/2021, time 7:00-8:00 pm

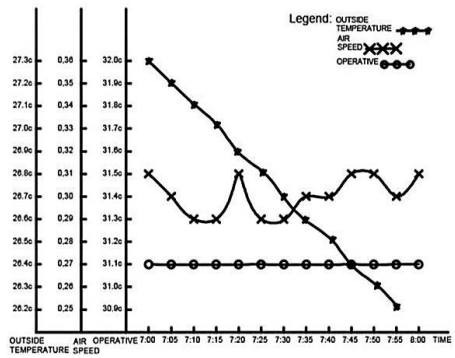
Appendix B. Measurement thermal comfort of classroom on 15/September/2021

SMK Seri Serdang classroom



15/September/2021, time 7:00-8:00 am

SMK Taman Desaminium classroom



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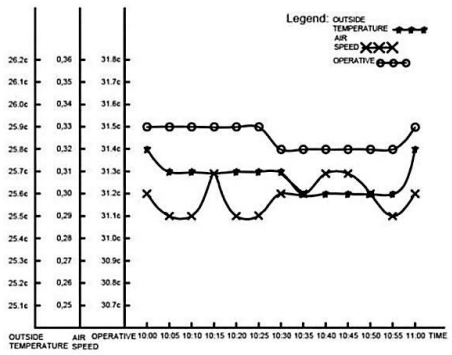
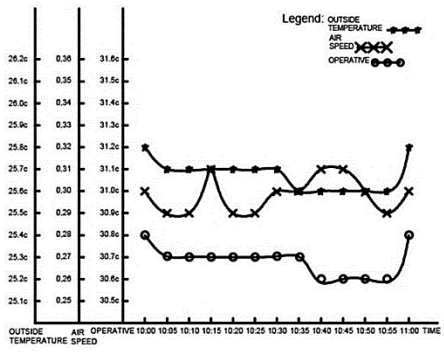
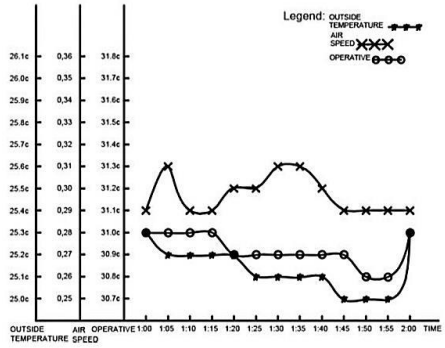


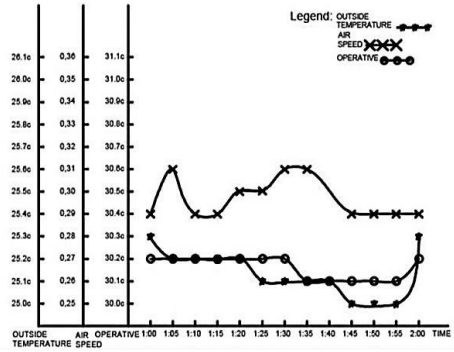
15/September/2021, time 10:00-11:00 am



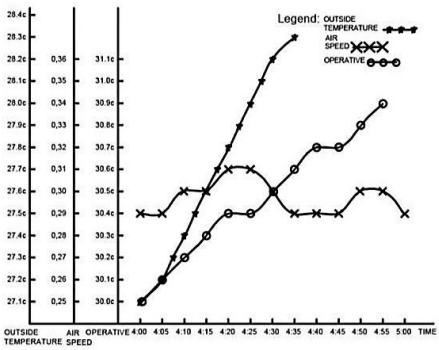
15/September/2021, time 10:00-11:00 am



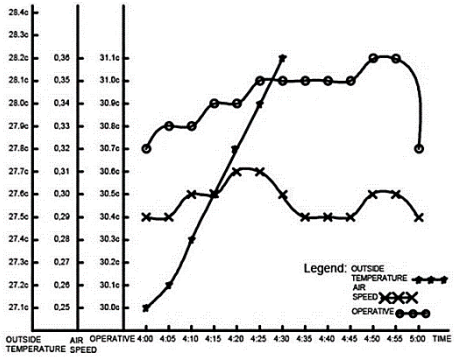
15/September/2021, time 1:00-2:00 pm



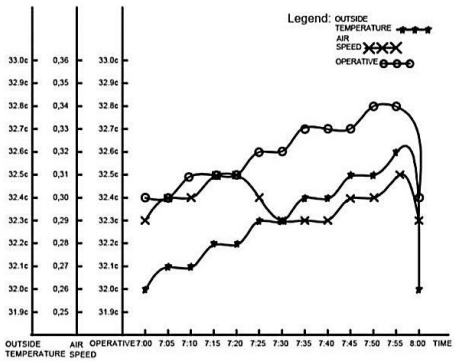
15/September/2021, time 1:00-2:00 pm



15/September/2021, time 4:00-5:00 pm



15/September/2021, time 4:00-5:00 pm



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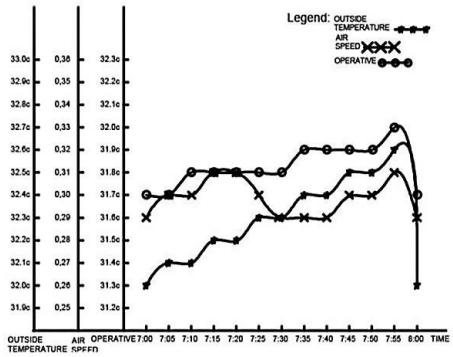

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