Jurnal Kejuruteraan SI 6(1) 2023: 299-309
https://doi.org/10.17576/jkukm-2023-si6(1)-26

Performance of Lower Ventilation Opening to Improve Air Change per Hour in Classroom at Tropical Humid Region (Case Study: Palembang City)

Tri Woro Setiati [a], Sandra Eka Febrina[b]* & Fajar Sadik Islami[a]

[a]*Department of Architecure, Facultay of engineering, Universitas Tridinanti Palembang*

[b]*Department of Architecure, Facultay of engineering, Universitas Indo Global Mandiri*

**Corresponding author: sandra.ek@uigm.ac.id*

Received 9 March 2023, Received in revised form 19 May 2023
Accepted 7 July 2023, Available online 31 October 2023

ABSTRACT

Fresh air circulation in a room had an impact on indoor air quality. In today's pandemic, good fresh air circulation is one of the main strategies to prevent viruses from spreading through air molecules. A good ventilation opening design influences indoor air exchange. This research conducts a test on lower ventilation opening design that can maximize natural ventilation performance in a classroom. This test aimed at a recommendation for schools in the tropical humid region so they can hold offline learning with low virus spreads. Natural ventilation optimization should be a solution because not everyone can afford mechanical air filters or virus killers. This research used an experimental method. Computer simulation test variables were classroom openings consisting of existing openings, new outlets/openings, and lower ventilation opening. Parameters of observation are wind velocity, air circulation pattern, and air change per hour. This evaluation compares the experiment result to Air Change per Hour (ACH) threshold limit provision required in Indonesia. The result of the experiment shows outlet/opening addition provides a better impact on ACH escalation than with only existing classroom opening. And when the existing opening is closed, lower ventilation opening had good performance in achieving the ACH threshold limit provision requirements which were 9,8 ACH.

Keywords: Lower opening ventilation; classroom; tropic humid

INTRODUCTION

A lot of research on the spread of the COVID-19 virus has been carried out, both in the fields of health, psychology, to architecture. The field of architecture is one of the related sciences to help reduce the spread of the virus strategy. This is because the field of architecture is related to the formation of a space that becomes a shelter for human activities. Due to the Covid-19 pandemic, many building designs or rooms have been reviewed to minimize the spread of the virus, even though the 5M Health Protocol (wearing mask, social distancing, handwash, crowd avoidance, and travel less) issued by Indonesian Ministry of Health is one of the self-protection strategies and very important as a form of controlling the source of the virus.

However, these processes only regulate activities and limit human interaction. In other cases, the increase in the spread of the virus occurred in indoor clusters such as offices, restaurants, and classrooms. This condition triggers the need for prevention strategies other than the 5M process, namely adaptation of buildings and the environment in which humans are active. The urgency of the evaluation and the addition of recommendations from this program is very vital due to the insistence on the implementation of face-to-face learning in schools, both from kindergarten to high school level. To support this policy, the government has issued guidelines for preparation for the implementation of direct learning during the pandemic. This guide is a complete guide to the terms and conditions of the health protocol in school. However, there is still a lack of review in preparing a safe and healthy school environment and building for children to learn and socialize during the pandemic.

In the direct learning guide published by the government through joint decree of 4 Indonesian Ministry (Ministry of Education, culture, research, and technology; Ministry of Religious Affairs; Ministry of Health; and Ministry of Home

Affairs) in 2021, one aspect that highlighted is the provision of adequate ventilation. However, this has not been explained in detail and practically applied in the classroom. The evaluation parameters have not been properly and effectively regulated. Based on several basic theories related to natural ventilation systems, a strategy that can be done to optimize ventilation performance is the theory of cross ventilation. With this optimization, a conducive classroom environment will be created during the pandemic. In its implementation there are two things that become the main targets, namely (1) reducing the opportunity for the spread of the virus in the classroom; (2) the achievement of comfortable learning spaces for students and teaching staff. In the end, users who feel comfortable when doing activities in buildings, and these conditions are expected to increase concentration in learning and reduce symptoms of sick-building-syndrome which can interfere with body immunity.

This study focuses on evaluating and recommending adequate natural ventilation designs to reduce the potential for virus spread in classrooms. The initial evaluation aims to determine the weakness of existing ventilation which initially depends on the use of air conditioning (AC). Some schools, especially private schools, have been accustomed to using air conditioning to provide thermal comfort for students and teachers. This causes the openings for natural ventilation to tend to be small and only on one side of the wall (as the inlet and outlet). The use of the principle of cross ventilation is rarely used in classrooms that use air conditioning, because the air exchange is done automatically by the mechanical device. This condition is of course not in accordance with the needs during the pandemic. Figure 1 shows how the virus transmission process occurs in a classroom without natural ventilation.

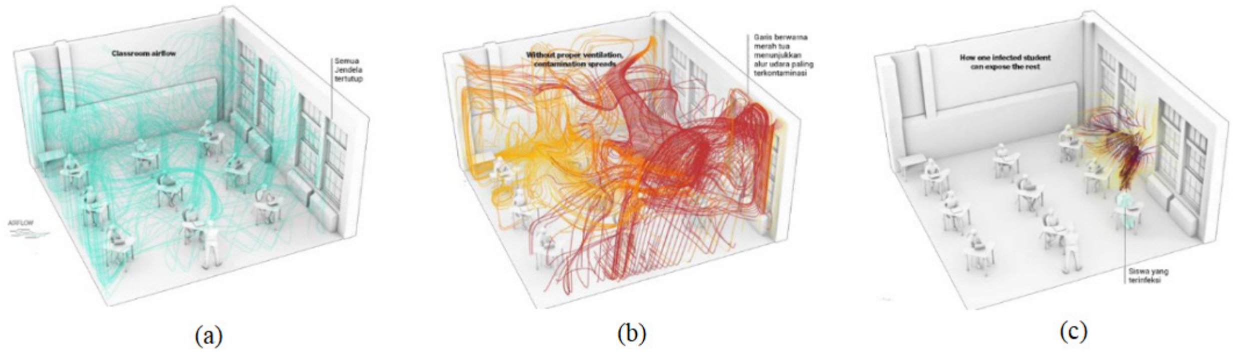


FIGURE 1. (a) close ventilation; (b) the airflow from infected students; (c) airflow pattern that spreads air that has been contaminated with virus-infected students. (Source: New York Times. https://www.nytimes.com/interactive/2021/02/26/science/reopen-schools-safety-ventilation.html)

Based on these problems, it is necessary to evaluate and recommend effective and efficient natural ventilation designs applied to schools that initially depended on air conditioning. This is because the most important approach to reduce indoor air pollutant concentrations is to increase natural air ventilation for fresh air exchange so that indoor pollutants can be released.

METHODOLOGY

The research method used is experimental with data collection. Data was collected by measuring wind conditions, temperature and particulate concentration in classrooms which using 45% sliding windows. Monitoring is carried out for 3 (three) days during the teaching and learning process (07.15 – 11.30 WIB) (Figure 5). Measurements use a room PM detector (Figure 3) and a digital anemometer (Figure 2) which can also measure air temperature. Measurements were carried out every 30 minutes by manual data collection. The object of study is a school located in the Commercial Area on the primary road in Palembang. The parameters of the classrooms observed consisted of room density (number of students and room area), length of study, area, and position of natural ventilation. Referring to the Regulation of the Minister of National Education (Permendinas) No. 24 of 2007 concerning Standards for School Facilities and Infrastructure, a maximum of 28 students and a classroom size of 7m x 8m (56m2) (Figure 4), the maximum density of classrooms is 2 m2/student. However, in pandemic conditions there is an adjustment to the maximum number of classrooms used by 50% of the number of students, so that the density can be double the standard value. For ventilation area standards based on the Decree of the Minister of Health Number: 1429/MENKES/SK/2006 the ventilation holes to ensure the flow of fresh air in the classroom are adequate.

FIGURE 2. Digital Anemometer

FIGURE 3. PM Detector

EXPERIMENT

In the implementation of the experiment, four conditions of ventilation in the classroom were observed. The four conditions tested were: (1) the existing condition of the classroom (without outlets); (2) existing windows open plus outlets; (3) the existing windows are open in addition to openings at the lower level (lower ventilation) and outlets; (4) closed windows, there is lower ventilation outlets. The experimental research tactics summary is shown in Table 1.

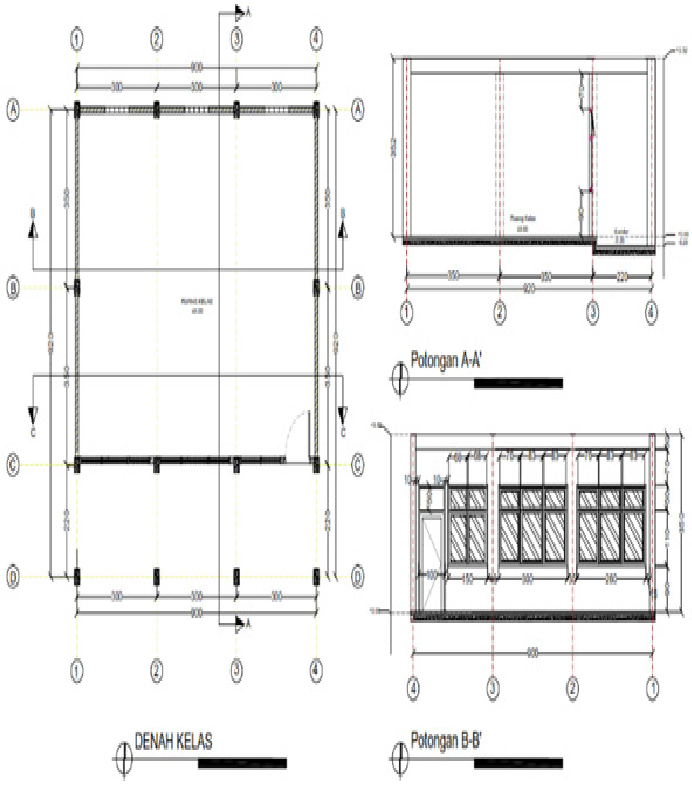


FIGURE 4. Classroom Plan

FIGURE 5. Measurement execution

TABLE 1. Experimental research tactics summary

Title	Setting	Treatment condition	Outcome Measures
Performance of lower ventilation to improve air change per hour in classroom at tropical humid region	Computer Simulation	Open-close window Adding outlet Adding lower ventilation	Average of wind speed (m/s) ACH Airflow pattern

The classroom model is modeled according to the existing conditions of the observed classroom, which is 7.00 x 9.00 m with a floor to ceiling height of 3.5 m. The opening of the classroom consists of a door (0.9 x 2.00m); sliding window with a net opening area of 2.72 m², as well as the addition of lower ventilation at the level of 30 cm above the floor surface and a total area of 0.9 m² (Figure 6).

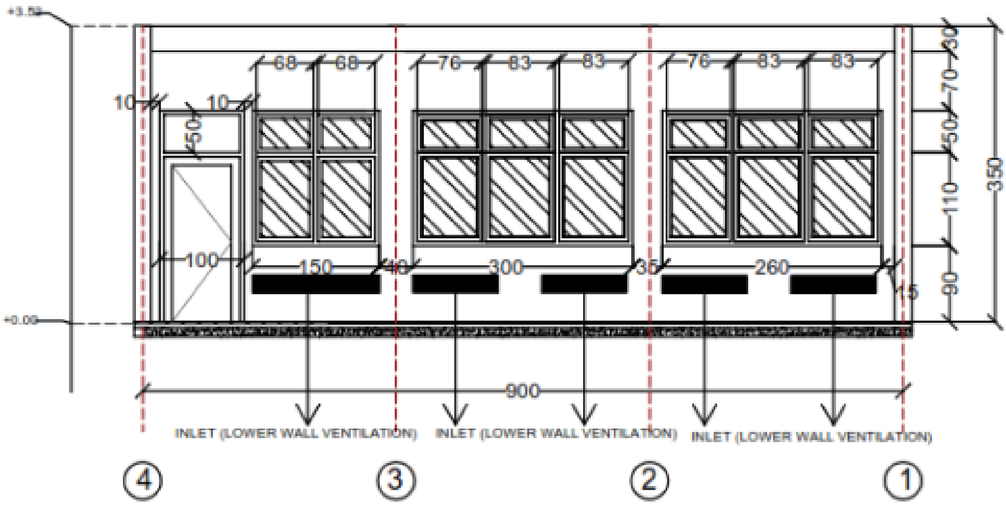


FIGURE 6. Experiment Classroom model with Lower Ventilation opening.

In the experimental model, an outlet is also added which is on the opposite wall from the inlet. The position of the outlet is the position of the glass block that has been installed in the existing condition of the classroom. The outlet level is at a height of 2.1 m above floor level. With an outlet area of 0.364 m² x 3 outlets (Figure 7).

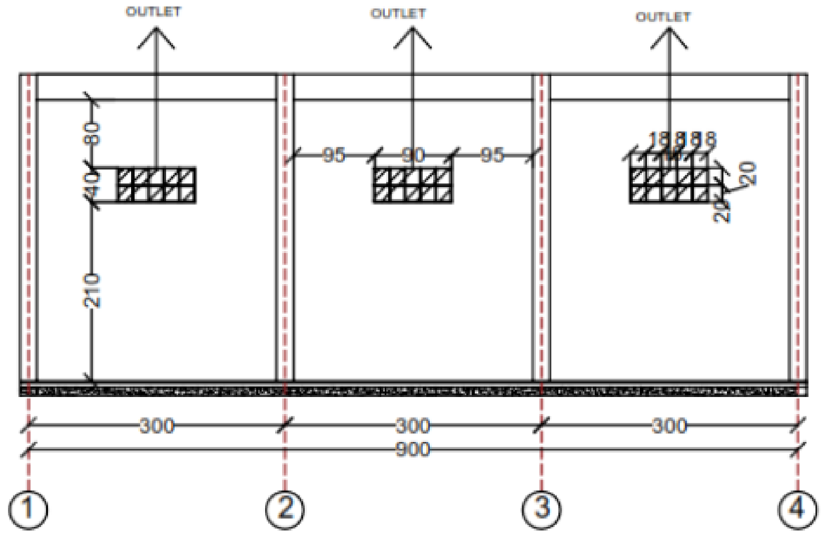


FIGURE 7. Experiment Classroom model with adding outlet/opening.

The experimental process uses CFD simulation which settings as shown in Figure 8 with boundary layer provisions or modeling limits such as several related references (Zhang et al. 2022; Thendean et al 2019; Guo et al. 2022, Angelopoulos et al. 2016). The input data used in the simulation process is a data measurement that has been carried out in the study object environment. The data used is the external wind speed at the initial boundary layer with units of meter per second (m/s).

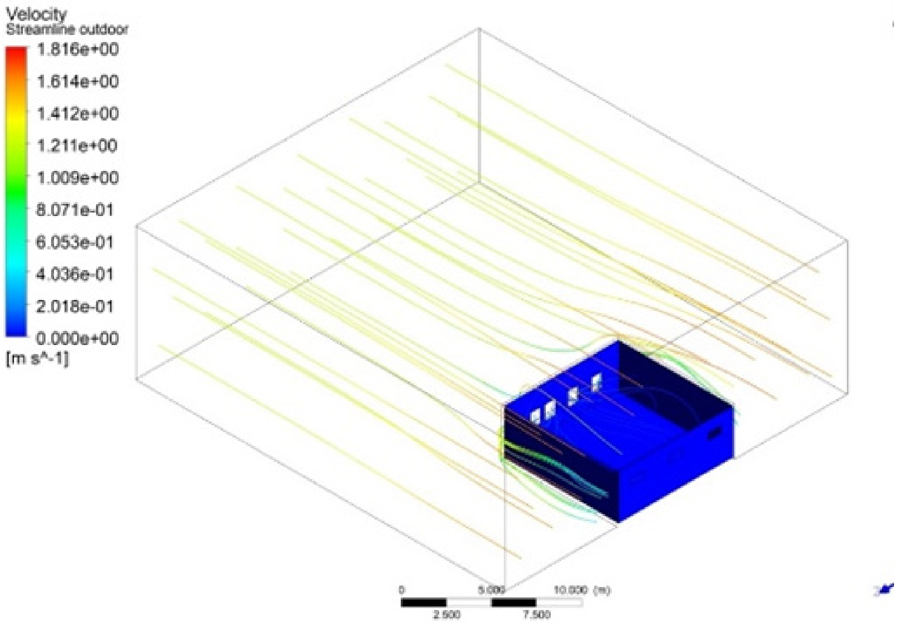


FIGURE 8. Setting boundary layer

RESULTS AND DISCUSSION

CLASSROOM AIR QUALITY EVALUATION

The results of the measurement of classroom air quality with PM 2.5 particulate concentration indicator; PM 1.0 and PM 10 show a non-significant difference between the two spaces (Figure 9). Higher particulate concentration values occur in rooms with natural ventilation. This condition is motivated by the fact that the particulate concentrations of PM 2.5 and PM 10 are emissions that come from outside (Ding et al. 2022). A room with wide windows will have the opportunity to receive more pollution from outside.

The evaluation was carried out by comparing the Threshold Value (NAV) within 24 hours with the value of PM 2.5 (25 ug/Nm3) and PM 10 (50 ug/Nm3) (Inaku and Novianus 2020). Based on the threshold value, classroom air quality with respect to PM 2.5 is above NAV in a certain period. This will be a follow-up evaluation to be able to find a control strategy. PM 2.5 indoors is affected by vehicle emissions; the contribution of vehicle emissions was found to be higher in schools located close to highways (Rosalia et al. 2018). The results of other studies also show that there is a positive correlation with an increase in the prevalence of asthma and rhinitis in school children with high concentrations of PM 2.5 in the classroom (Annesi-Maesano et al. 2012). Evaluation for concentrations of PM 1.0 and PM 10 are still in safe condition or below the applicable threshold value.

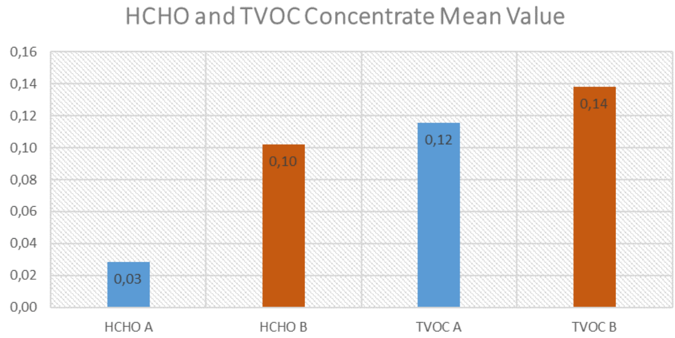


FIGURE 9. Comparison of concentrate value at Classroom A and B

Further evaluation was carried out by comparing the concentration values of HCHO (formaldehyde) and TVCO (total volatile organic compound) which are chemical pollutants found in finishing with a mixture of thinner in the room (Talarosha 2017). Figure 10 shows that lower levels of HCHO and TVOC occur in the classroom that uses natural ventilation. This condition is affected by the higher wind speed in classroom A, due to the open windows. This provides an opportunity for fresh air exchange. Different conditions in classroom B, which has low airflow, resulted in higher concentrations of HCHO and TVOC.

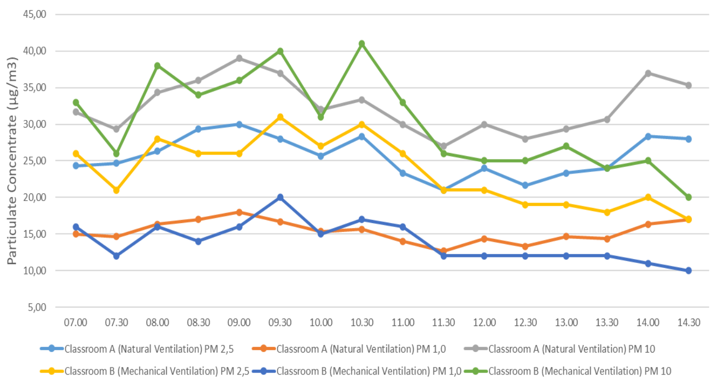


FIGURE 10. Comparison of HCHO and TVOC concentrations at Classroom A and B

TEMPERATURE AND HUMIDITY EVALUATION

The air temperature and humidity evaluated in this study consisted of three data, namely outdoor space, classroom A (natural ventilation) and classroom B (artificial ventilation/mechanical ventilation/using air conditioning). The measurement results (Figure 11) show that there is a difference o T between the outer and inner spaces of 3.7°-3.9°. The average room temperature in classroom A and B is still in the comfortable warm temperature range (25.8 – 27.1°C) (Karyono 2013). Analysis and comparison of the air temperature conditions in classroom A and B shows that there is no significant difference. Classroom A room has a tendency of higher and fluctuating air temperature than Classroom B. It is because the indoor air temperature is directly affected by the outdoor temperature due to the open window. Open windows result in a higher opportunity for heat to enter through radiation and convection. Unlike Classroom B, the air temperature is lower and more stable because it has been conditioned by mechanical devices in the form of air conditioning.

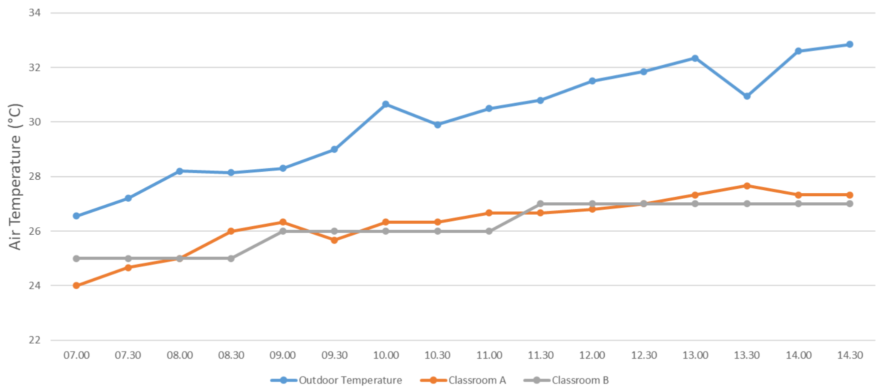


FIGURE 11. Average outdoor temperature, indoor temperature at Room A and B

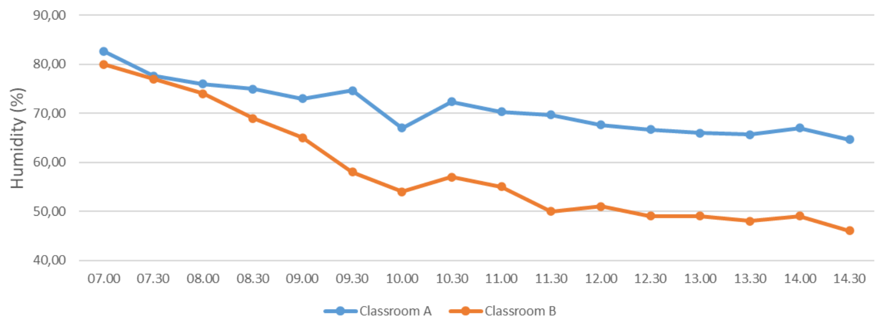


FIGURE 12. Comparison of humidity condition

The results are the same as the measurement of air temperature, the humidity in classroom A and B has the same trend as the air temperature. Classroom A will spontaneously follow the humidity fluctuations from the outside due to the direct relationship of outdoor and indoor air due to open windows. Following the air temperature in classroom B, the humidity also tends to be stable because it has been regulated by a mechanical device.

Evaluation of the air temperature and humidity in the classroom shows that Classroom A has more volatile conditions because it is directly affected by the outside room. However, when viewed from the side of temperature alone, the temperature range that occurs in classroom A is still in the warm-comfortable category. For humidity conditions in classroom A, a strategy for reducing humidity can be carried out with the help of a fan. For the evaluation of classroom B, of course it will provide better thermal comfort, because the comfort conditions can be adjusted directly through the air conditioning.

AIRFLOW EVALUATION

Analysis and evaluation of air flow or wind speed is the main point to be able to conclude how the distribution of air flow is better than the two observed classes. Related to air flow, of course, the ventilation system is very influential. Ventilation refers to the process of supplying fresh air to the indoor environment and draining polluted air (Winata et al. 2021). Figure 13 shows the air movement that occurs in the outdoor room, classroom A and class B. Air movement that occurs in classroom A is quite volatile and the speed is higher than class B.

Based on the results of wind speed measurements in the class inlet area, the average speed that occurs is around 0.225 m/s. The wind speed conditions in classroom A still meet the recommended health threshold set by ASHRAE (2019). With an air speed of 0.255 m/s, it provides a greater opportunity for air exchange. However, the reverse condition with a classroom B with an average air speed of 0.02 m/s with the windows and doors closed will result in the room not having the opportunity to get fresh air. If it is associated with the current pandemic conditions, the condition of classroom B has the potential to spread the virus more easily and the time for the spread of the virus will be longer.

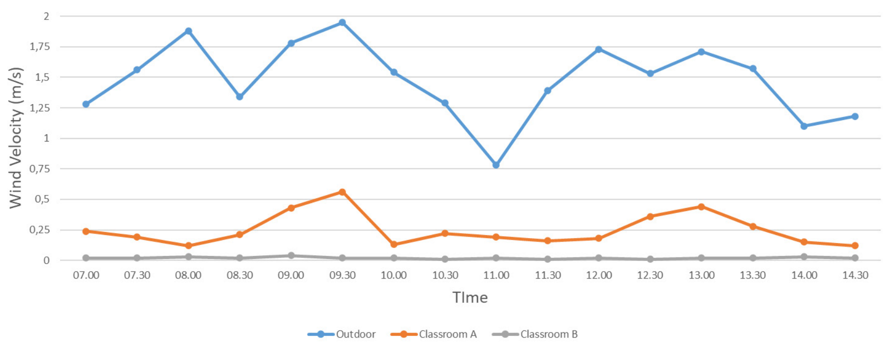


FIGURE 13. Comparison of airflow condition

SIMULATION RESULTS

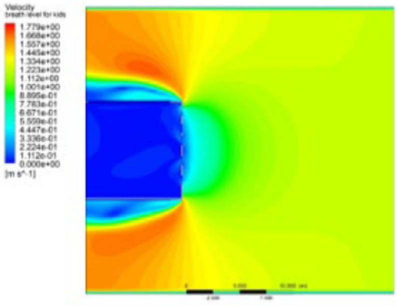
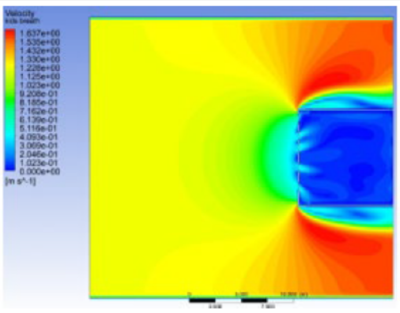
At this stage, experimental models are made which are tested in computer-assisted simulations using fluid dynamic computing. The model is made into 4 (four) based on the results of the analysis on the measurement data. The measurement results show that natural ventilation provides better air exchange opportunities than the use of air conditioning. This can be seen from the condition of the wind speed that occurs at the inlet and the center of the room. However, the measurement of particulate concentrations showed that the result is higher than normal thresholds for particulates PM 2.5 and PM 10 were sourced from dust and vehicle emissions. Based on the results of the condition analysis, the classrooms on field motorcycle taxis are limited by vegetation in front of the class from 0.0 m ground level to 0.7 m ground level. This condition provides an opportunity to test several types based on the level position of the floor surface. In the existing condition, the ventilation used is ventilation at the middle level of the wall, which is 0.90m above the floor surface. There are sliding or sliding window types. The perfect opening area is 2.72 m². In the experimental process, testing was carried out on one condition where the classroom was added with lower ventilation 35 cm above the floor surface. The lower ventilation dimension is 0.2 x 1.0 m, and there are 5 openings in each class. Table 2 shows 4 (four) models tested in this study.

The simulation results show that outlets in classrooms have a significant effect on increasing the air flow rate and air change per hour. Comparison of the results was carried out on Model 1 which is the existing condition and Model 2 which added an outlet (Table 3). The air flow contour shown in Table 3 that the existing Model 1 has smaller chance for air change per hour (ACH) than Model 2 which has added an outlet. Classroom conditions with a small value of air change per hour will increase the risk of spreading the virus in the room (Winata et al. 2021). This condition should be avoided. Evaluation of model 2 shows the possibility of ACH having a higher frequency. This is quite good, because the air in the room can be replaced with fresh air, thereby minimizing the surface contaminated by viruses or pollutants.

TABLE 2. Classroom model description

	Sliding window condition	Lower Ventilation at 35 cm below the floor	*Outlet*
Model 1 (existing)	Open	No	No
Model 2	Open	No	Yes
Model 3	Open	Yes	Yes
Model 4	Close	Yes	Yes

TABLE 3. Comparison of Model 1 and Model 2

		Velocity at outlet	*Air Change per hour*
Model 1		0 m/s	0.3 ACH
Model 2		1.12 m/s	15.4 ACH

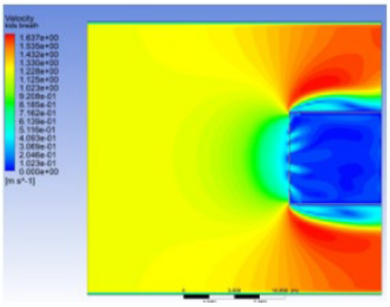
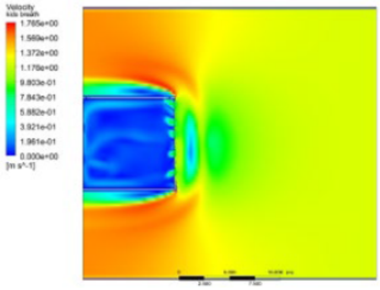
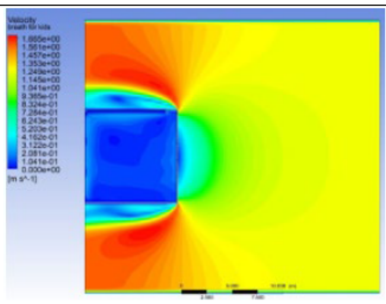
The comparison of the 2 models above shows that there is a positive effect with the addition of outlets. Comparison was then carried out on 3 modified models to analyze the effectiveness of the opportunity for virus spread and pollutant contamination, especially PM 2.5 and PM 10 which became a problem in the measurement results at the beginning of the study.

Table 4 shows the pattern of air flow, velocity at outlet and air change per hour that occurred in the 3 modified models.

The simulation results in models 2, 3 and 4 show that lower ventilation has a large enough performance when the sliding window is closed. While in Model 3, the open windows and the use of lower ventilation opening have decreased performance with the ACH value. Although in the three models the ACH that occurs in the room is above the reference value of ASHRAE (2019) and PERKEMENKES (2023).

Airflow conditions that occur in Model 4 when analyzed further, with the windows closed but the room ACH is still fulfilled will minimize the entry of PM 2.5 and PM 10 particulate concentrations from vehicle emissions and dust. This is because, at the front of the classroom that is parallel to the lower ventilation level, there is vegetation that can function as an air filter. So that the air entering through the lower ventilation tends to be cleaner than the air entering through the window at the middle level of the wall.

TABLE 4. Comparison of Model 2, 3 and 4

		Velocity at outlet	*Air Change per hour*
Model 2		1.12 m/s	15.4 ACH
Model 3		0.99 m/s	13.7 ACH
Model 4		0.73 m/s	9.9 ACH

CONCLUSION

Testing of these 4 ventilation models proves that there is a ventilation design strategy that can be applied to classrooms in schools located in the humid tropics. Lower ventilation opening and its uses in a room provide a better opportunity for the exchange of fresh air in the room. Because with the lower ventilation outlet/opening, cold air can flow through the lower level and with the temperature difference that occurs, the speed of air flow in the room will be higher. The high velocity of air movement will increase the potential for fresh air exchange. While the outlet has an important role as a path to circulate hot air and air that has been deposited in the room.

ACKNOWLEDGEMENT

The author would like to thank BOPTN Research through the Directorate of Research, Technology, and Community Service (DRTPM) for the financial support provided through the Beginner Lecturer Research Program grant.

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