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Study Recommendations to Achieve Thermal Comfort in an Educational Building

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Abstract

This paper evaluates natural ventilation effectiveness in one fully dependent Air Conditioned-Educational Building in Depok to recommend potential passive cooling approaches toward user thermal comfort. This study involves building surveys to measure the temperature and humidity of three selected classrooms, A, B, and C, with varying configurations and capacities. Airflow simulation using Computational Fluid Dynamics (CFD) is done under two conditions: open and closed doors. A set of parameters, which are room configuration, type of window, and ventilation strategy, are set to evaluate natural ventilation aspects. The site survey indicates that only one classroom with an area of 92 sqm facing to the southside is classified as efficiently warm (Room A). The simulation demonstrates that cross-ventilation only occurs when the door is opened. The parameters indicating shape, dimension, type, and area of natural ventilation matter, show that the building's natural ventilation is ineffective in providing thermal comfort. This study recommends that the building's natural ventilation be placed according to the direction of the airflow, adding vertical fin elements, and increasing the openings by more than 5% area from the floor area.

INTRODUCTION

One of the elements that affect building design is the climate. The heat that enters a building through its exterior walls is a harmful climate factor in a country with tropical climates, as in Indonesia. The magnitude of the heat and humidity propagation, along with the lack of wind movement, raises the temperature inside the building (Hamzah et al., 2017). The physical environment of a classroom has a tight relationship with students' learning and health since they spend about a third of their day in the classroom (Giuli et al., 2012). Unacceptable thermal circumstances brought on by extremely high or low temperatures correspond to distraction and a decrease in focus, which impedes the progress of the learning process (Jia et al, 2021). On the other hand, optimal thermal conditions can increase typing and thinking efficiency by 47.4% and 32.6%, respectively. Considering that educational facilities are to provide the ideal learning environments for students and teachers, classrooms should be created to enhance focus and encourage learning while being climate-responsive. Therefore, maintaining an appropriate indoor classroom environment is essential for the comfort and health of learning (Liu et al., 2021).

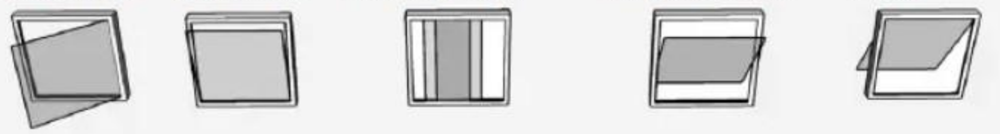
According to ASHRAE Standards 55 (2004), thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Thermal comfort parameters might differ, but most researchers use the same parameters to measure thermal comfort in a building (Zamri et al, 2019). Environmental and individual factors primarily influence thermal comfort. Environmental elements include air temperature, velocity, and humidity (Priya & Kaja, 2016). SNI 03-6572-2001, an Indonesia National Standard Procedures for proposing ventilation systems and air conditioning in buildings, states that there are three thermal comfort zones for the tropics. Those are cool and comfortable (between 20.5~22.8°C), optimal comfort (between the effective temperature of 22.8~25.8°C), and warm (between the effective temperature of 25.8~27.1°C). According to SNI 03-6572-2001, to maintain comfortable circumstances, air velocity should not be more than 0.25 m/s and is preferable to be lower than 0.15 m/s, while the suggested relative humidity in tropical regions is also between 40%

and 50% to fulfill the criteria created by SNI 03-6572-2001. The relative humidity for a place with many people inside, for example, a meeting room, can still be as high as 55 to 60%. These factors significantly affect how thermal comfort is measured in a naturally ventilated classroom.

The natural ventilation system is crucial to limit the usage of mechanical ventilation, which uses much energy, and to provide thermal comfort. It is believed that one of the most efficient passive cooling strategies is natural ventilation, especially for cooling dominant climates, which may give building occupants comfortable thermal conditions and a healthy environment (Liping & Hien, 2007; Santamouris, M. & Allard, F., 1998). In some circumstances, buildings need more air circulation to compensate for a room's excessive temperature and humidity levels and satisfy the requirement for fresh air from outside (Geetha & Velraj, 2012). The three primary purposes of the room ventilation system are to (a) ensure that the air in the room changes, (b) make the people comfortable, and (c) cool the materials and furniture situated in the room (Hamzah et al, 2017), and the open ventilation in hot and humid conditions is proven to enhance thermal comfort (Liping & Hien, 2007). In this case, Lippsmeier (1980) believes that the cross-ventilation factor is crucial for a room's comfort because, in the humid tropics, building orientation parallel to the significant wind direction is more crucial than solar radiation shielding.

Designing a building with natural ventilation requires a thorough knowledge of airflow patterns and the impact of the building's surroundings. The objective of the effectiveness of natural ventilation is to ensure adequate clean air circulation throughout the building's interior. A building’s natural ventilation performance is impacted by both external and internal factors. Examples of external factors are often related to the velocity of external wind, external wind direction, and the presence of external barriers such as vegetation and walls, as well as other elements (Gao & Lee, 2011). In order to promote natural ventilation in another way, a variety of internal factors can be used, including; (a) building orientation, (b) shape & size of openings to the wind direction, (c) overhangs and sun shading devices, (d) type of windows, (e) arrangement of plants to the inlet (Wardhana, 2018). However, one of the drawbacks of natural ventilation is that it should not be employed in noisy or unclean situations. Additionally, it works well in spaces with openings on both sides or a depth-to-height ratio of less than 3 (Bluyssen, 2009). He admits that recovery from heat is essentially impossible. The airflow rate also varies depending on the weather; therefore, it is crucial to maintain effective control to meet the ventilation needs. Utilizing self-regulating (pressure-controlled) ventilation grills is an alternative method (Bluyssen, 2009).

There are many kinds of window openings available (Figure 1.). According to Roetzel et al. 2010, different window opening styles have different characteristics in terms of weather protection, maximum ventilation rates that can be achieved, adjustability of opening widths, and potential furniture interference caused by opening windows. The evaluation of those six different window types for various climatic circumstances concluded, based on opening percentages and angles, side-hung windows opening inward were preferred above sliding windows partially covered by panes and top-hung windows opening outward for normal opening angles (Roetzel, 2010).



Properties of different window types when opened at a typical angle	Side hung, opening to inside	Bottom hung, opening to inside	Sliding, opened pane always covers part of window	Horizontal pivoted, lower part opening to outside	Top hung, opening to outside
Weather protection	–	+	–	0	0
Max. achievable ventilation rate	+	–	0	+	0
Adjustability of opening size	+	–	+	+	+
Flexibility for placement of furniture	–	+	+	0	+

Fig. 1. Type of windows openings evaluation. Description of symbols: -, poor; 0, medium; +, good
(Source: Roetzel et al. 2010)

Monica et al. (2022) used CFD simulation to evaluate the level of airflow in a classroom at an educational building during the COVID-19 pandemic towards the pandemic’s recommendation on natural ventilation. The result showed that the fastest wind speed in the class ranged 0.12 m/s to 0.44 m/s while the slowest wind speed was 0.01 m/s to 0.12 m/s. It happened due to the placement of space openings intersection (Monica et al., 2022). Bay et al. (2022) has carried out a study to investigate the relationship between indoor environmental conditions and natural ventilation in historic religious structures. The findings revealed that when the proposed night ventilation scenario maintains air temperatures and relative humidity levels within an ideal range for occupant comfort and building and artwork preservation, mechanical system operation can be reduced, especially during springtime (Bay et al., 2022). Using CFD simulations, Lestari & Muazir (2021) assessed the type 36 building designs from the viewpoint of the airflow through the unit. The findings demonstrated that rooms with the placement of vents facing each other, even if they were in different rooms, produced continuous airflow without encountering turbulence. Tanumidjaja et al.

(2021) has examined the effectiveness of façade geometry with recessed balcony by using CFD simulation analysis combined with energy performance evaluation. The result found that recessed balconies were found to be an unsuitable for condenser unit placement on a façade where many factors, such as the stagnation of air movement and hindering the dissipation of high air temperature contributed to heat re-entry from condenser units into the building's interior. Omrani et al. (2017) investigated how the ventilation mode affected the thermal comfort and ventilation efficiency of a high-rise case study unit. The outcome highlighted that cross ventilation performs significantly better than single-sided ventilation. Cross ventilation offered comfortable indoor thermal conditions, more than 70%, compared to 1% when single-sided ventilation was used. In the end, although many researches discussed about the impact of natural ventilation on indoor spaces, some gaps in linking natural ventilation with passive approaches for providing user thermal comfort, reducing the building's reliance entirely on mechanical ventilation need to be observed. Therefore, this paper aims is to evaluate natural ventilation effectiveness in one fully dependent Air Conditioned-Educational Building in Depok to recommend potential passive approaches to provide user thermal comfort. The result is expected to improve the building's natural ventilation performance by creating more airflow penetration through the openings and allowing cross-ventilation without disturbing ongoing educational activities.

METHODOLOGY

Lechner (2015) states that a building must have effective natural ventilation to achieve thermal comfort. This study uses three methods to evaluate the effectiveness of natural ventilation performance in the case study building (Figure 2). First, data was generated from on-site measurements using a data logger to obtain the temperature and relative humidity values. The aim is to observe whether the current condition of the case study is by the criteria as SNI 03-6572-2001 states or not. The second one is generating data from Computer Fluid Dynamics (CFD) simulation using ANSYS, which can handle issues of heat transmission and fluid (Phadnis & Shalunke, 2014). This is expected to analyze how airflow penetrates inside the building, how much influences the configuration and volume of the room, and the effectiveness of the existing opening arrangements in the educational building.

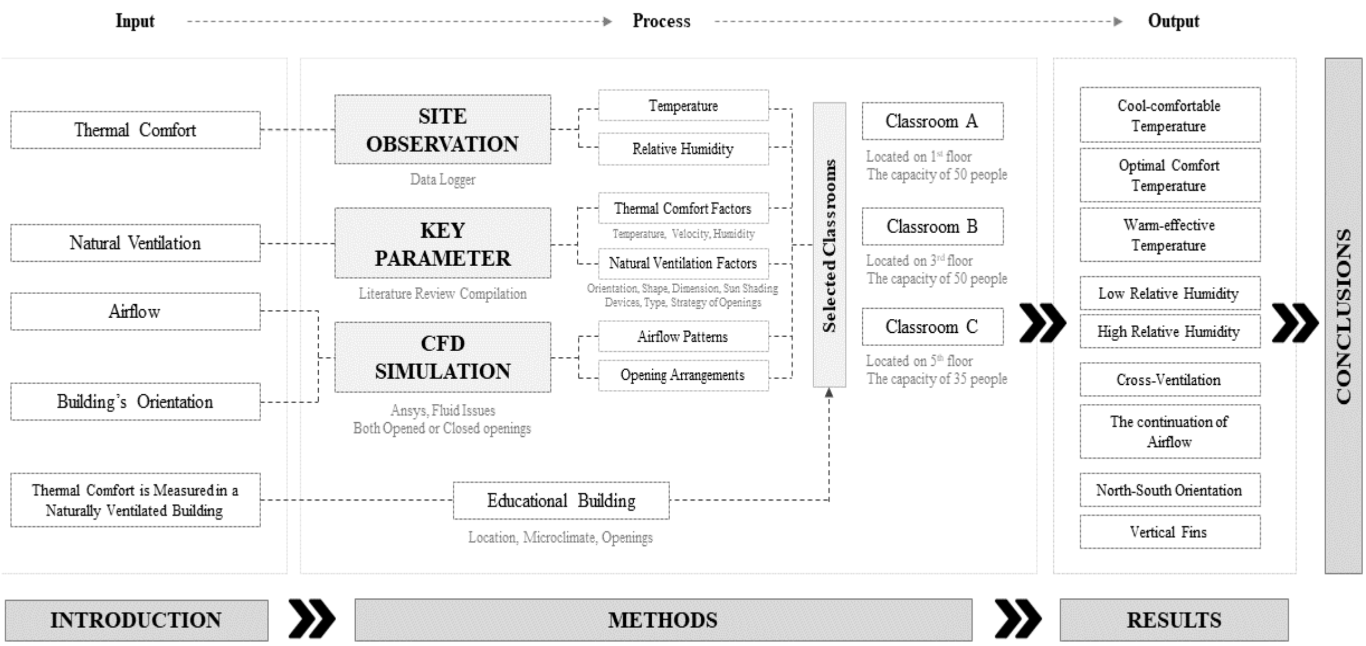


Fig. 2. Research Framework (Source: Author)

The last method for data generation in this research is using key parameters by combining the literature mentioned above, the aim is to analyze whether the natural ventilation aspects in the case study are by the provisions. These data generations are then carried out in 3 selected classrooms, which are called classrooms A, B, and C, having different variations of configurations and capacity of each classroom. The classes are selected based on the height of the building. Classroom A is located on the first floor, on the ground of the building, with a capacity of 50 people and faces towards the south side. In contrast, classroom B is located on the third floor, which is in the middle of the building's height. This has the same capacity and face. Lastly, classroom C is located on the fifth floor, which is the highest room in the building in terms of height. This has a capacity of 35 people and is the only selected class that faces toward the north side. These classes were selected to evaluate whether different configurations of each class affect the effectiveness of natural ventilation in the building.

Case Study: S Building, Depok

S building is an educational building located in UI Campus Street, Kukusan, Beji District, Depok City, West Java, 16424 Faculty of Engineering, University of Indonesia. Figure 3 shows the block plan, showing an existing 6-story structure on the north side of the building and approximately four meters long; on the other side, surrounded by lush trees. The building consists of classrooms for students in the Faculty of Engineering, restrooms, lecturer rooms, meeting rooms, janitor, seminar rooms, and prayer rooms. The block plan also shows the climate condition. According to www.meteoblue.com, from 13th to 27th August 2022, the strongest wind blows on the site are from East, East North East (ENE), and East South East (ESE) by approximately 10 to 15 km/h. According to Beaufort Scale discovered by Francis Beaufort in 1805, those values belong to a light breeze, in which leaves and small twigs are in constant motion, and the wind extends a light flag.

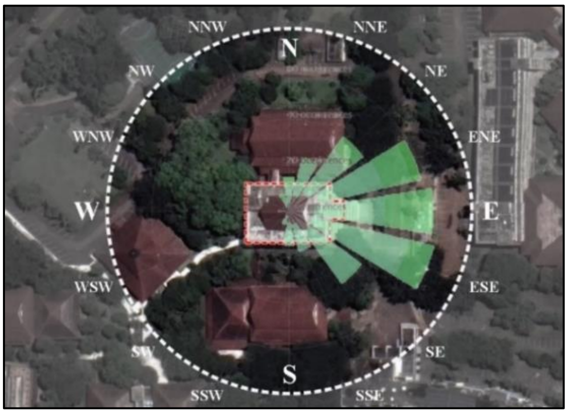


Figure 3. S Building Block Plan & Microclimate (Source: Author)

Moreover, the building façade (Figure 4) was designed with windows called Casement top-hung 75% and overhang horizontal louvers in the horizontal plane. Those windows are the only source to let natural light and air penetrate the building since it was designed with a double-loaded corridor. On the opposite side of the windows, there is a door (Figure 5) which the type of it is a double-acting door with two leaves.

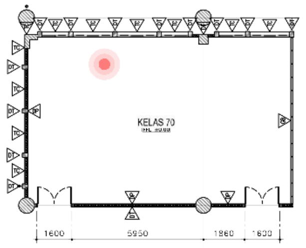
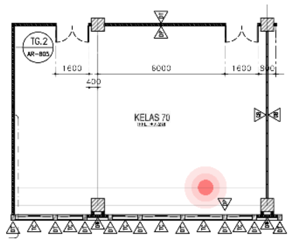
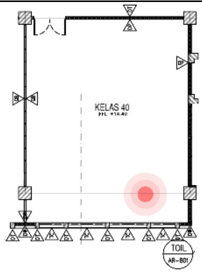
Fig. 4. S Building South Façade & Windows

Fig. 5. Two leaves double-acting door

The Placement of the Data Logger

A data logger tool was used while surveying the site. Two indoor environmental variables were recorded on the tool, which are the air temperature (°C), and relative humidity (RH) (%). According to Badhiye & Chatur (2011), a data logger is an electronic device that measures temperature, relative humidity, and other characteristics like voltage and pulse using analog and digital measurements and programming techniques. The data logger receives the input value of thermocouple temperature, and humidity, provided to the database and analysis software and utilized to store and analyze the monitored data. Table 1 shows that the data logger was located inside at a distance of fewer than two meters from the windows of each chosen class, and observation was carried out for 5 minutes in each selected classroom. While measuring, the condition of the building was free from the occupants; AC was turned off, windows were opened, and the door on the opposite side was closed.

Table 1. The placement of Data Loggers

	Classroom A	Classroom B	Classroom C
Data Logger Location			
	The data logger was placed inside and less than two meters from the windows of each chosen class.		

(Source: Author)

ANSYS as a CFD Simulation

The other method is a CFD Simulation using Ansys Student 2022 Version. Ansys can address a wide range of structural and non-structural issues. These issues include heat transmission and fluid issues, static and dynamic structural analysis (linear and non-linear), and acoustic and electromagnetic issues (Phadnis & Shalunke, 2014). In this study, the software is used on the side of fluid issues to examine the airflow distribution and movement inside the classrooms by having two setting conditions. These conditions were utilized to examine how an obstruction affected the patterns of airflow that occurred in the space since walls and other interior obstructions significantly impact airflow patterns. The first condition is that windows are opened, but the door is closed. The objective of this situation is to evaluate whether cross-ventilation occurs. The other condition is that both windows and doors are opened. The aim is to ensure that the opening area of the door is sufficient. The door is the airflow outlet which is placed on the opposite side of the windows.

Key Parameters

In this context, key parameters were considered to evaluate the performance and availability of natural ventilation in the selected classrooms by a combination of external and internal factors (Table 2). The parameter of external include temperature, air velocity, and humidity in the classroom. In contrast, the parameter of internal includes windows' orientation, shape, dimension, sun shading device, types, arrangement of vegetation, the strategy of natural ventilation, area, and direction of windows. If those parameters achieved the indicators, the result is marked as 'v' with green color on the table. Conversely, if the result of the parameters does not achieve the indicator, it is marked as 'x' and yellow color.

Table 2. Key Parameter of Thermal Comfort and Natural Ventilation Factors

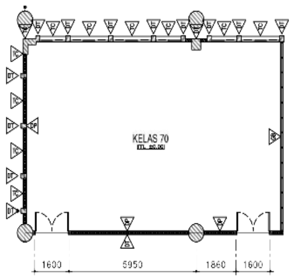
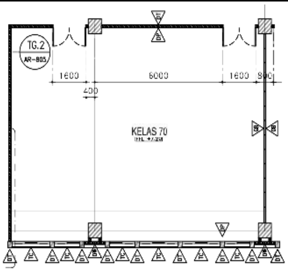
No.	Parameter	Indicator	Purpose
		External Factors	
1	Temperatures	Optimal comfort between the effective temperature of 22.8~25.8°C. (SNI 03-6572-2001)	To achieve thermal comfort in terms of dry air temperature, especially in tropical areas (SNI 03-6572-2001)
2	Air Velocity	It should not be greater than 0.25 m/s and preferably less than 0.15 m/s. (SNI 03-6572-2001)	The airspeed falling overhead in order to maintain comfortable conditions for users (SNI 03-6572-2001)
3	Humidity	40%~50%. (SNI 03-6572-2001)	The recommendation value to achieve thermal comfort in tropical areas (SNI 03-6572-2001)
		Internal Factors	
4	Orientation	Oriented north-south (Lippsmeier, 1980)	To prevent much exposure to solar radiation (Lippsmeier, 1980)
5	Shape	A horizontal aperture or aperture square inlet. (Chenvidyakarn, 2007)	The ability to produce free airflow has a modest scale and can withstand small wind loads (Lechner, 2015)
6	Dimension	The outlet opening is larger than the inlet. (Busato, 2003)	Better utilization of the winds in internal environment and in greater change rates per hour (Sacht & Lukiantchuki, 2017)

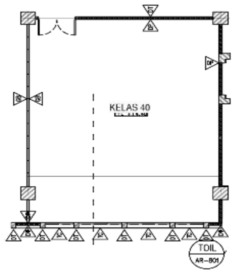
No.	Parameter	Indicator	Purpose
7	Sun shading devices	Overhang Horizontal Panel, Overhang Horizontal Louvers in Horizontal Plane, Overhang Horizontal Louvers in Vertical Plane, Overhang Vertical Panel, Vertical Fin, and Eggcrate (Geens & Griffiths, 1990)	Sun shading device is a designed passive device that can block the sun's beams in order to block the incoming heat (Purnama, 2020)
8	Type of Window	Side-hung casement type, which can enter the airflow of 90% of the window area (Godfrey, 1974)	Interferes both in the resistance offered to the airflow and in direction and intensity (Sacht & Lukiantchuki, 2017)
9	Arrangement of Vegetation	Vegetation around the window (Latifah, 2015)	The ability to bend the direction of the air (Latifah, 2015)
10	The strategy of Natural Ventilation	Single-side ventilation, Cross Flow ventilation, Stack Ventilation & Top-Down Ventilation (Ohba & Lun, 2010)	To observe which strategy of the innate aspects of wind movement to collect (Ohba & Lun, 2010)
11	Number	Not less than 5% of the floor area of the room needs ventilation (SNI 03-6572, 2001)	To provide adequate airflow due to temperature differences and the pressure differential created by the wind outside a building (SNI 03-6572, 2001)
12	Direction	Facing a walled courtyard of the appropriate size or area that opens (SNI 03-6572, 2001)	To provide adequate airflow due to temperature differences and the pressure differential created by the wind outside a building (SNI 03-6572, 2001)

Classrooms Selection

Three classrooms were selected to analyze the air circulation through the openings (Table 3). The first one is classroom A, which is located on the first floor and faces towards the south side with a capacity of 50 people. When needed, windows can be opened when the room is filled with occupants, and there are two Air-Conditioners available. There is a massive space in front of the door leading to a yard. The second one is classroom B, which is on the third floor of the building that faces towards the north side, with the same capacity. Some windows can be opened, and there are two Air-Conditioners are available. The double-loaded configuration is used, allowing classrooms to be located between corridors. Lastly, classroom C is located on the fifth floor of the building, facing the north side with a capacity of 35 people. Some windows can be opened with Air-Conditioner(s) inside the class.

Table 3. The three selected classrooms' documentation and layout plan

Selected Classroom Name	Detailed Information	Documentation	Layout Plan
Classroom A	Area: 92 sqm Location: 1st Floor Distance from Window to Door: 7.7 meters		
	Classroom A has an area of 92 sqm with a capacity of 50 people and has window openings with casement top-hung 75% type on the north side of the building. There are two doors on the opposite side to get to the lobby area on the first floor of the building.		
Classroom B	Area: 90 sqm Location: 3rd Floor Distance from Window to Door: 10 meters		
	Classroom B has an area of 90 sqm with a capacity of 50 people and has window openings with casement top-hung 75% type on the south side of the building. There are two doors on the opposite side to get to the main corridor of the third floor of the building.		

Selected Classroom Name	Detailed Information	Documentation	Layout Plan
Classroom C	Area: 70 sqm Location: 5th Floor Distance from Window to Door: 10 meters		
	Classroom C, which has an area of 70 sqm with a capacity of 35 people, has window openings with casement top-hung 75% type on the south side of the building. There are two doors on the opposite side to get to the main corridor of the fifth floor of the building.		

RESULT AND DISCUSSION

Measurement of air temperature and relative humidity in three selected classrooms (Table 4) revealed that classroom A's average temperature is 26.18°C, which according to SNI 03-6572-2001, is in the warm, effective category. Relative Humidity is 71.01%, beyond the range of 40%~50% recommended by SNI 03-6572-2001 for tropical areas. In contrast, the average temperature of classroom B is 28.63 °C which exceeds the criteria in SNI 03-6572-2001. The relative humidity of the class is 57.3% which is still beyond the range of 40%~50 % recommended by SNI 03-6572-200. Classroom C shows an average temperature of 28°C, which also exceeds the criteria in SNI 03-6572-2001. The Relative Humidity is 57.2% which is still beyond the recommendation range of 40%~50% for tropical regions.

Table 4. Observation using Data Logger in Classroom A

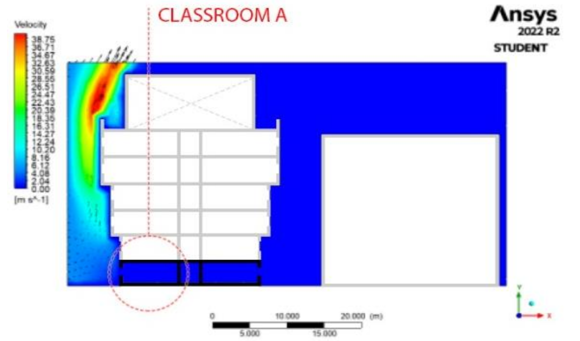
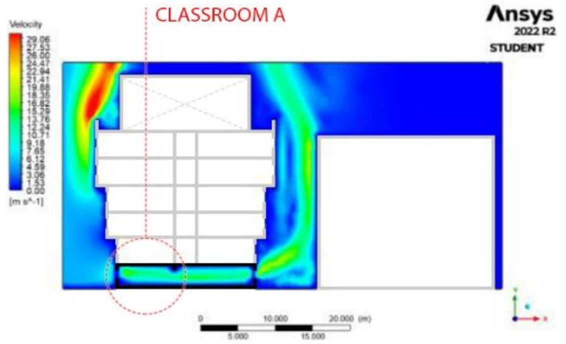
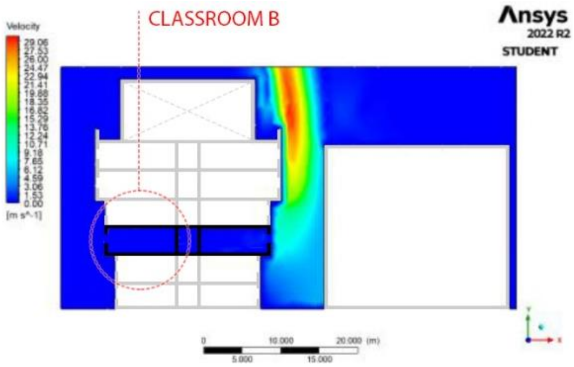
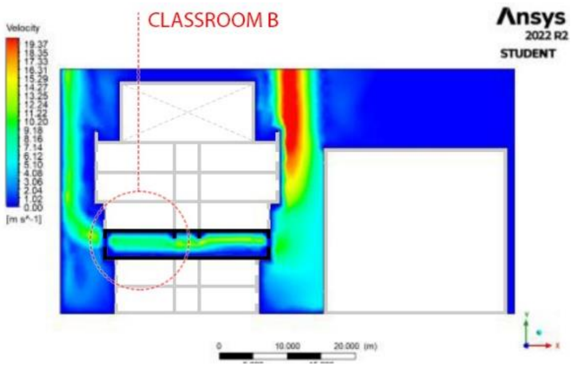
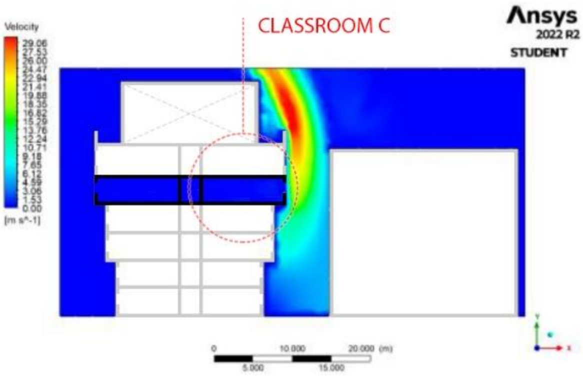
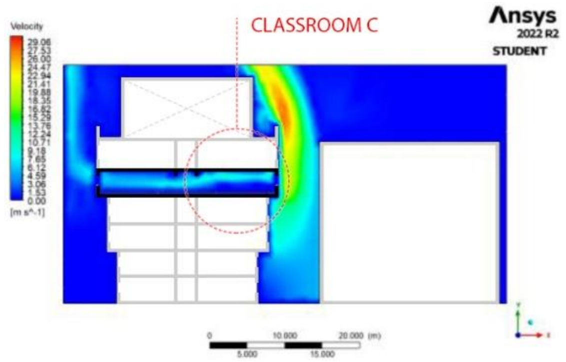
No	Date Time, GMT +07.00	Required Temp, °C	Temp, °C	Required RH, %	RH, %
		Plot Title: Classroom A			
1	2022-03-30, 10.46.44		26.06		71.00
2	2022-03-30, 10.51.44	25.80~27.10	26.30	40~50	71.02
	Average		26.18		71.01
		Plot Title: Classroom B			
1	2022-03-30, 11.44.15		28.47		58.35
2	2022-03-30, 11.49.15	25.80~27.10	28.79	40~50	56.33
	Average		28.63		57.30
		Plot Title: Classroom C			
1	2022-03-30,12.18.02		27.83		62.65
2	2022-03-30, 12.23.02	25.80~27.10	28.17	40~50	51.79
	Average		28		57.2

Qualified to Required Temp or RH
Unqualified to Required Temp or RH

Moreover, the airflow simulation is shown in Table 5. In classroom A, it is demonstrated that even though there is a door opening leading to a foyer, which generates strong winds, the wind could not enter the classroom as the door was closed. Likewise, classrooms B and C have door openings facing corridors; the wind is demonstrated cannot enter either space as the doors were closed. In fact, these results show the same statement in accordance with Hawendi & Gao (2016), in which airflow can be influenced by the opening factor in the building, one of them is the placement of the openings that the airflow within it. On the other hand, the situation appeared to be different when doors were opened, resulting in the wind entering all classrooms since there was intense pressure coming to the side of the window opening. In other words, the simulation shows that the natural ventilation in the building is ineffective due to air circulation because the wind is caused by the flow of the air from high pressure to low pressure.

Lastly, critical parameters of thermal comfort and natural ventilation factors that are already arranged in the method are evaluated based on the condition of the selected classrooms (Table 6). The result shows that thermal comfort factors are not achieved in terms of air temperature, air velocity, and relative humidity. In other words, the value of the parameters of the rooms exceeded the value recommended by SNI 03-6572-200. For natural ventilation factors, this shows poor performance as parameters of the shape, dimension, type, and area of openings were not fulfilled. The existing apertures are vertical, while the parameter should be a horizontal aperture or square inlet, which is better than vertical (Chenvidyakarn, 2007).

Table 5. Existing Airflow Condition on 3 Classrooms' Sections

Classroom	Windows Open – Door Close	Window Open – Door Open
A		
B		
C		
Notes	Even though the windows on the side of the wind blows are opened, while the door in the middle of the floor is closed, the wind cannot enter those rooms since they do not allow cross-ventilation.	When all openings are opened, wind flows from one room to another.

(Source: Author)

Furthermore, Busato (2003) states that a greater airflow rate can be achieved when the outlet opening is larger than the inlet, but in fact, the classroom door as an airflow outlet has a smaller dimension than the airflow inlet. The other aspect that is not fulfilled is the existing type of window, which is a casement top-hung with an area of 75%. According to Godfrey (1974), a suitable type of window allows airflow with the most significant percentage, namely the side-hung casement type, which can let an airflow of 90% of the window area. The last one is that the existing building's ventilation area was only 2.6% of the floor area, far below SNI 03-6572-2001 recommendation of not being less than 5% of the room's floor area needing ventilation. Some aspects were fulfilled, such as the orientation of the opening that was pointed to the north and south side; as stated by Lippsmeier (1990), the opening orientations to the east and west are known to expose the most solar radiation. Another fulfilled aspect is in terms of the sun shading device of the building, which is a horizontal overhang panel with a dimension of 100 mm depth & 211.5 mm height. Geens & Griffiths (1990) explain that horizontal overhang panels, overhang horizontal louvers in the horizontal plane, overhang horizontal louvers in the vertical plane, vertical overhang panels, vertical Fin, and Eggcrate are the recommended sun shading devices.

Table 6. Existing Condition Based on the Key Parameters

No.	Parameter	Indicator	Existing Condition	Mark
External Factors				
1	Temperatures	Optimal comfort between the effective temperature of 22.8~25.8°C. (SNI 03-6572-2001)	28.08~28.79°C	x
2	Air Velocity	It should not be greater than 0.25 m/s and preferably less than 0.15 m/s. (SNI 03-6572-2001)	No wind on the date when we measured	Not Defined
3	Humidity	40%~50%. (SNI 03-6572-2001)	58.35% ~71.95%	x
Internal Factors				
4	Orientation	Oriented north-south (Lippsmeier, 1980)	Oriented north-south	**v**
5	Shape	A horizontal aperture or aperture square inlet. (Chenvidyakarn, 2007)	Vertical	x
6	Dimension	The outlet opening is larger than the inlet. (Busato, 2003)	Typical window (view from inside). Dimension: 60 mm x 115 mm & sill height is 100 mm. The outlet is not larger than the inlet.	x
7	Sun shading devices	Overhang Horizontal Panel, Overhang Horizontal Louvers in Horizontal Plane, Overhang Horizontal Louvers in Vertical Plane, Overhang Vertical Panel, Vertical Fin, and Eggcrate (Geens & Griffiths, 1990)	The Building Classroom's typical window (view from outside) Overhang horizontal panel dimension: 100 mm depth & 211.5 mm height	v
8	Type of Window	Side-hung casement type, which can enter the airflow of 90% of the window area (Godfrey, 1974)	Casement top-hung 75%	x
9	Arrangement of Vegetation	Vegetation around the window (Latifah, 2015)	Vegetation around the window can bend the direction of the air	v
10	The strategy of Natural Ventilation	Single-side ventilation, Cross Flow ventilation, Stack Ventilation & Top-Down Ventilation (Ohba & Lun, 2010)	Potential for cross-flow ventilation, but the doors and windows are always closed, so the cross-flow ventilation is not working.	v
11	Number	Not less than 5% of the floor area of the room needs ventilation (SNI 03-6572, 2001)	16.56 m^2 / 640 m^2 = 2.6%	x
12	Direction	Facing a walled courtyard of the appropriate size or area that opens (SNI 03-6572, 2001)	Facing the open area	v

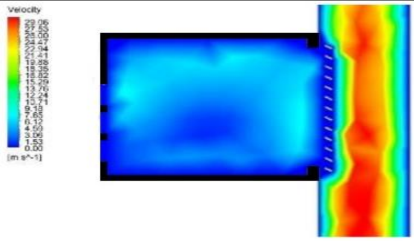
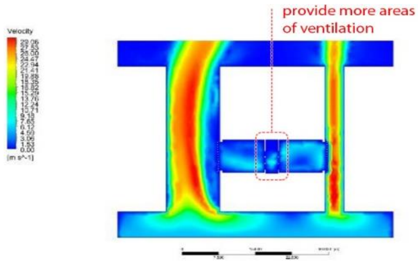
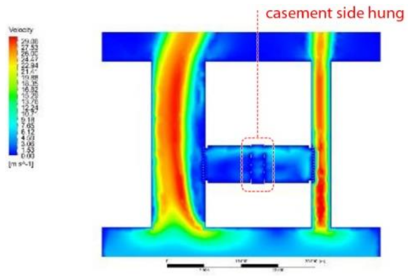
Noted: Fulfilled (v) or Unfulfilled (x) (Source: Author)

Furthermore, the building also has vegetation around the window that can bend the direction of the air (Latifah, 2015) and has the potential for cross-flow ventilation (Ohba & Lun, 2010) by opening both windows and doors of the classes. Lastly, the direction of the building's aperture that faces the open area also fulfilled this particular aspect. According to SNI 03-6572-2001, apertures should face a walled courtyard of the appropriate size or open area that opens.

Potential strategies of the passive cooling approach for S Building (Table 7) are discussed here to maximize natural ventilation. For the classrooms that have openings facing north and south, also the direction of the wind blowing from the east side sun shading devices like vertical fin elements could be an option if the wind direction is on the east or south sides, which can cause heat radiation to the building. These vertical fin elements can bend the airflow direction, penetrating the building through the openings. Moreover, given that there is only about 2.6% natural ventilation area in each class, it is advised to enhance the natural ventilation area to more than 5% in each class's floor area, according to SNI 03-6572-2001. This enhancement can be proposed to the opposite wall of the current openings in the classes to allow cross-ventilation. Lastly, it is recommended to have a horizontal-shaped window than the existing vertical one, to maximize the cross-flow ventilation. Furthermore, the window type of casement side hung is also advised as it can allow airflow of 90% of the window area.

Even though there are no users, and the windows and doors are open, only Classroom A, dimensionally bigger than classrooms B and C, falls under the warm, effective category following SNI 03-6572-2001. The relative humidity of those classrooms was also beyond the range of 40%~50%, as recommended by SNI 03-6572-2001. According to the CFD simulation performed using Ansys, the natural ventilation in the building is ineffective as the wind moves from high air pressure to low air pressure. Most of the wind cannot penetrate the rooms, as the direction of the wind on the site does not direct to the windows. In other words, this circumstance prevents the airflow from producing a continuous pattern. However, natural ventilation performance in these classrooms works effectively only if both windows and doors on the opposite side are open and produce cross-ventilation. This assertion is consistent with the result of a study conducted by Lestari and Muazir (2021), who discovered that placing ventilation facing each other, even if they are in different rooms, will produce continuous airflow without turbulence. From all the findings, the building's natural ventilation operates effectively regardless of how big or small the classroom is, but natural ventilation in the classrooms is ineffective due to a lack of opening areas and the factors of natural ventilation that correspond to the research's critical parameters above.

Table 7. Potential Strategies of Passive Cooling Approaches for S Building

No.	Strategy	Condition	Simulation (Floor Plan)	Purpose
1	Sun Shading Devices – Vertical fin elements	Proposing vertical fin elements on the building façade and windows as the central opening in all classrooms		To bend the airflow direction and protect solar radiation that enters through windows.
2	Enhancing the Number of Natural Ventilation Areas	Proposing more areas of natural ventilation facing corridor access – Condition of all windows is opened, and the door is closed		To allow cross-ventilation to occur as advised by SNI 03-6572-2001 to provide an area of natural ventilation of more than 5% of the floor area.
		Proposing a casement side hung with horizontal-shaped window		To allow cross-ventilation to occur as it can allow airflow of 90% of the window area.

CONCLUSION

Natural airflow entering the classrooms through the windows influences the comfort of the occupants in the room. In summary, this study found that the natural ventilation of the S building is not effective in providing thermal comfort, which is why the classrooms require Air Conditioners to achieve thermal comfort. The factors of the ineffectiveness of natural ventilation in the building are the use of vertical apertures as the shape of the airflow inlet. The dimension of the airflow outlet aperture, in which a double-acting door acts as the only outlet opening, is smaller than the airflow inlet aperture. The use of window type is casement top-hung, where it does not have the ability to bend the direction of the outside wind into classrooms. Lastly, the ratio of the natural ventilation area to the floor area of the class is still minimal. All these factors affected the pattern of the airflow entering through the inlet apertures in the building.

This study recommends two potential strategies of passive cooling approaches for the building in order to maximize its natural ventilation. Firstly, by proposing vertical fin elements on the building façade, the elements can bend the airflow direction to enter the classrooms and protect against solar radiation that enters through windows. Secondly, it is proved that proposing more areas of natural ventilation, more than 5% of the floor area as advised by SNI 03-6572-2001, such as windows on the other side facing corridor access or foyer that stays open, this can allow cross-ventilation to still occur once the door is closed due to ongoing class. In the end, it is expected that the findings of this research would be beneficial for architects to strengthen basic considerations whenever designing educational buildings. Moreover, when its goal is to achieve thermal comfort and provide an ideal and climate-responsive learning environment.

In further research, potential aspects can be explored to investigate the building's natural ventilation performance by considering the user's perception since this research was done by observing from both simulation and measurement. Moreover, the effect of noise from outside of the rooms can also be considered for future research, where the factor can affect the performance of natural ventilation, especially in educational buildings.

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