AIRFLOW EVALUATION FROM NATURAL VENTILATION IN CLOSEDROOM AS PREVENTION OF COVID-19 TRANSMISSION

Case Study: Architecture Studio Room, Faculty of Civil Engineering and Planning Building, UII

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ABSTRACT*: The COVID-19 pandemic has had an impact on educational activities. Lecture activities were forced to be carried out online during the pandemic, but unfortunately did not produce good output. While face-to-face lectures involve many people in a closed room. So that in this pandemic condition requires room conditions that support also to minimize the transmission of the COVID-19 virus. Meanwhile, natural ventilation is one of the recommended ways to create the condition of the room. The Architecture Studio Room in the FCEP UII Building still relies on air conditioning to help circulate air in the room. While the room is the room that is most often used as a lecture room for UII architecture students. This study evaluates the architectural studio room in the FCEP UII Building with a focus on ACH and wind circulation. The results show that the room is still far below the standard, so it is necessary to modify the opening to achieve the recommended lecture room standard during the pandemic.*

Keywords: airflow evaluation, natural ventilation, closed room, COVID-19 transmission

INTRODUCTION

Background

The COVID-19 pandemic has taken the world by storm since its first appearance in December 2019 in Wuhan, China. SARS-CoV-19 is the virus that is the leading cause of this pandemic. Its spread is so fast that it can instantly paralyze human activities in various parts of the world. Within a year of its appearance, 83 million people were recorded as infected with the SARS-CoV-2 virus.

Various researches related to this virus began to emerge as an effort of Infection Prevention and Control (IPC). From various existing studies, WHO published an article entitled "Modes of Transmission of Virus Causing COVID-19: Implications for Infection Prevention and Control (IPC) Precaution recommendation" posted on March 29, 2020, includes available scientific evidence regarding transmission. SARS-CoV-2. The article stated that there were eight modes of transmission of the SARS-CoV-19 virus. One of which was through droplets and aerosols (WHO, 2020). University of Indonesia (UI) Epidemiology Expert Pandu Riono (2020) explained that the spread of the coronavirus is higher in closed rooms, such as fitness rooms or offices with poor ventilation. Most buildings with enclosed spaces focus on using HVAC (Heating, Ventilation, and Air Conditioning), where the concept can cause many problems such as excessive energy use and is also not environmentally friendly. According to WHO, aerosol transmission can occur in closed spaces such as restaurants, nightclubs, and other spaces where speaking, shouting, and singing are possible.

However, at the university level, research conducted at the PGRI Yogyakarta University shows that students feel this continuous online learning is very ineffective. It is caused by repeated boredom that reaches a saturation point. In addition, the material that students can absorb is less than half, plus the ability of lecturers and students to use the internet is still low (Dewantara & Nurgiansah, 2021). Seeing the relatively low effectiveness of online lectures and the serious impact of online courses, many people have urged face-to-face lectures to run again, especially in lecture activities that involve practice. However, this still has to be reconsidered, seeing the potential impact carried out when classes are again conducted face-to-face.

In architecture, the use of natural ventilation in buildings can impact the health of its users. Research shows the role of natural ventilation in preventing the spread of viruses during a pandemic. Natural ventilation has helped to contain the spread of SARS (Severe Acute Respiratory Syndrome) in 2003 and also in cases of the spread of flu in Mexico and America in 2009 (Ohba & Lun, 2010). It can happen because the air circulation in the building becomes healthy. After all, it continues to use new air. In addition, cross-ventilation can provide thermal comfort to building users. The application of total air circulation is also in line with recommendations from the WHO (World Health Organization) regarding improving the quality of ventilation in buildings.

The wind from natural ventilation that moves in the building through an opening is the effect of differences in temperature or pressure. Natural ventilation takes advantage of the high air pressure on one side of the building (inlet) so that the wind will come from that direction towards the other side of the building with low pressure (outlet). So that the air that enters the building is not trapped and only moves from one corner of the room to another. Natural ventilation occurs in openings such as doors, windows, and open spaces in buildings. Cross ventilation as a method of channeling air can flow air from one side of the building to another. That way, the air circulation in the building becomes healthy because the air in the room is constantly changing and the user is always breathing new air.

The studio rooms spread on the 4th floor of the Mohammad Natsir Building, Faculty of Civil Engineering and Planning, UII are classrooms that are often used by architecture study programs in lecture activities, especially studio courses. In some studio rooms, they still rely on air conditioners as air conditioners in the room. This indicates that the natural air flow is still not good, causing thermal comfort to not be achieved. Poor airflow quality will also affect the potential for COVID-19 transmission.

In connection with the lectures which are expected to take place face-to-face, this study will evaluate the airflow in the architectural studio, Mohammad Natsir UII Building. It is hoped that with this research, the campus will be better prepared to open face-to-face lectures by preparing facilities for better room conditions during this pandemic.

Research Question

a. How are the airflow and the air changes (ACH) in the studio room from the natural ventilation related to the standard in the COVID-19 condition?
b. What is the design strategy so that the room can meet COVID-19 safety standards?

Research Aim

a. Find out the airflow and air changes (ACH) in the studio room from the natural ventilation related to the standard in the COVID-19 condition
b. Know the design strategy so that the room can reach the COVID-19 safety standard

Research Urgencies

From this research, it is hoped that higher education institutions will be more aware of the importance of the quality of indoor water circulation before resuming lecturing activities after the COVID-19 pandemic. The evaluation results in this study can be an input on how to design a good room strategy to minimize the possibility of spreading the COVID-19 virus and viruses related to other respiratory tract infections

LITERATURE REVIEW

The Principle of Airflow

Based on the principle, airflow (wind) moves due to the difference in pressure on the earth's surface. Wind tends to move from areas of high air pressure to areas of low air pressure. The wind that blows on the earth's surface occurs due to differences in the reception of solar radiation, resulting in differences in air temperature. The difference in air temperature is what causes the pressure difference, which eventually causes air movement. According to specific natural laws, air moves so that this air movement is relatively regular and predictable (Boutet, 1987).

Lechner, in his book '*Cooling, Heating, and Lighting*' explains several principles related to the airflow:

a. *Reason for the flow of air.* Air flows are caused by differences in temperature or becauseof pressure differences.
b. *Types of airflow.* There are four basic types of airflow: laminar, separated, turbulent,and eddy currents.

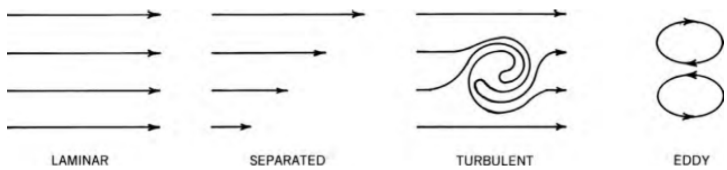


Figure 1 Three types of airflow
(Lechner, 2015)

c. *Inertia*. Air has mass, so its movement tends to be in a straight line. Therefore, if forcedto change the flow direction, this airflow will follow a curve and never form the correctangle.
d. *Air conservation*. Lines depicting airflow must be drawn continuously because the air approaching a building must be equal to the air leaving the building.
e. *Areas with high and low air pressure*. When the wind reaches the surface of the building, it will condense and create positive (+) (windward) pressure. Then the air will be deflected to the side of the building, creating a negative pressure (-) (leeward).
f. *The Bernoulli effects*. Increasing the fluid velocity will decrease its static pressure, thereby causing negative stress on the "venturi" tube restriction.
g. *Chimney effect*. The chimney effect is a combination of the Bernoulli effect and the venturi effect, where the exhaust of air from the building is carried out through naturalconvection.

Affecting Factors of Airflow

Several things affecting the airflow (direction and velocity) in a building:
Window Orientation and Wind Direction.

Winds exert maximum pressure when they are perpendicular to a surface, and the pressure is reduced about 50 percent when the wind is at an oblique angle of about 45°. However, indoor ventilation is often better with oblique winds because they generate more significant wind motion indoors.

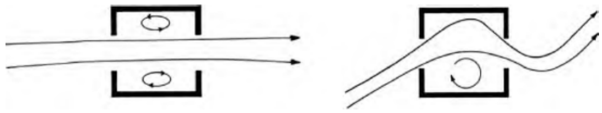


Figure 2 Opening orientation effect to the wind

a. Window Locations

Ventilation from windows on adjacent walls can be either good or bad, depending on the pressure distribution, which varies with wind direction (Lechner, 2015).

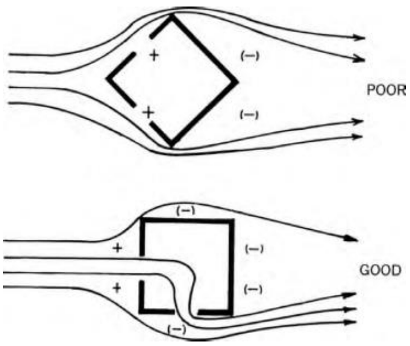


Figure 3 Influence of opening location to the wind

b. Window Types

The type and design of windows have a great effect on both the quantity and direction of airflow. Although double-hung, single-hung, and sliding windows do not change the direction of the airstream, they do block at least 50 percent of the airflow. On the other hand, casement windows allow almost total airflow, but they can deflect the airstream.

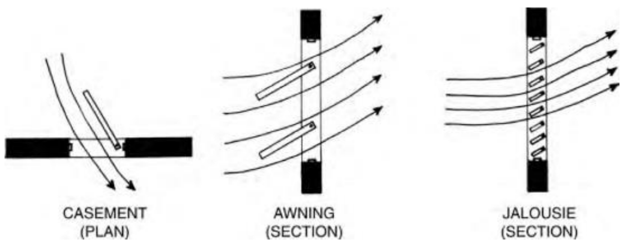


Figure 4 Influence of opening types to the wind

For the vertical deflection of the airstream, use a hopper, awning, or jalousie windows. These types also deflect the rain while still admitting air, which is very important in hot and humid climates. Unfortunately, with this kind of inclination, the windows deflect the wind upward over people's heads, which is undesirable for comfort ventilation.

However, if a large overhang keeps the rain out, then the slats of the jalousie windowscan be set to be horizontal (Lechner, 2015).

c. Opening dimensions

In conditions of limited wind speed and wind direction, a ventilation hole can be equipped with additional features to direct and increase the wind speed before entering the ventilation hole. The horizontal wing is a feature on the inlet installed horizontally to direct the wind from outside into the building (Erick Christ P.S).

The ventilation will be smoother if it is supported with adequate airspeed. In conditions of almost motionless air (near to 0 m / s), the window design must encourage faster movement or increase airspeed. It can be accomplished by selecting different window dimensions between the inlet and outlet (Figure x) or by choosing a window type with varying capabilities of airflow (Figure x) (Mediastika, 2002)

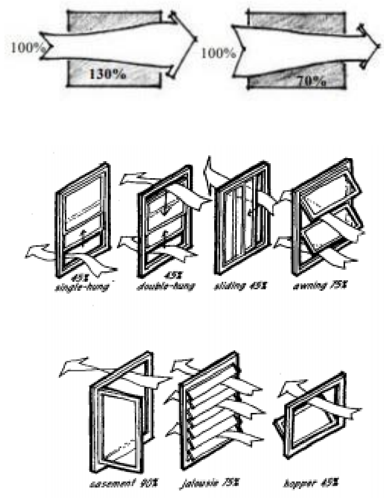


Figure 5 Effect of opening dimensions on wind flow

From the theories, the wind direction, type of opening, location of openings, the direction of openings, opening dimension, and opening position affect the quantity and direction of the wind. So, a building that can adjust the wind direction and the design of the opening components will create a good ventilation system.

Airflow Safety Recommendation During Pandemic Situation

The article published by WHO stated that there were eight modes of transmission of the SARS-CoV-19 virus (WHO, 2020)**.** Despite the difficulty of comparing and concluding which transmission route is the most important in a given situation, multiple studies provide strong evidence for virus transmission indoors, especially in crowded, poorly ventilated environments (Morawska et al., 2020).

A building called a healthy building provides good ventilation (either passive or active) inside (Daryanto, 2013). Good airflow in the room during this pandemic must avoid air recirculation as best as possible (Morawska et al., 2020). The air entering the room should only be replaced with new outside air. Even the use of a fan in the room needs to be conditioned. WHO, in its article, states that fans are helpful to help increase air change in a room. The hanging fan could demolish the air pockets in a room. However, if a room was visited by people from outside (can happen in the office, school, guests who come to the house), the fan is not recommended to be turned on (WHO, 2020). The opening is the most effective way to circulating the air.

Considering ventilation creates an urgency to assess the health building in the mid of COVID-19 pandemic, we can evaluate the building based on several published standards. Indonesian National Standards set the minimum opening for ventilation to be 5% of the room's total area (SNI Indonesia 6572-2001). Meanwhile, Minister of Health of the Republic of Indonesia Number 829 / MENKES / SK / VII / 1999 states that permanent natural ventilation or ventilation is at least 10% of the floor area.

In terms of the ACH (Air Changes per Hour), ASHRAE recommends school building have 5-6 ACH (not include lecture hall). Meanwhile, while dealing with the viruses, the recommendation for the ventilation rate is up to 8 ACH.

To calculate air exchange per hour (ACH) in a room/building can be using this formula:

$$ACH = (Q / V) \times 3600 \ldots\ldots \qquad (1)$$

Where Q is the level of natural ventilation (m3 / s), and V is the volume of the room (m3)The level of natural ventilation (Q) itself is obtained using the formula:

$$Q = 0.025 \times A \times v \ldots\ldots\ldots\ldots \qquad (2)$$

Where, A is the area of the opening (m2), v is the wind speed at the opening (m / s), and 0.025 is the multiplier (Erick Christ P.S).

Table 10.8 Air Velocities and Thermal Comfort

Air Velocity I-P fpm	Air Velocity I-P mph	Air Velocity SI m/s	Air Velocity SI kph	Equivalent Temperature Reduction* °F	Equivalent Temperature Reduction* °C	Effect on Comfort
10	0.1	0.05	0.2	0	0	Stagnant air, slightly uncomfortable
40	0.5	0.2	0.8	2	1.1	Barely noticeable but comfortable
50	0.6	0.25	1.0	2.4	1.3	Design velocity for air outlets that are near occupants
80	1	0.4	1.6	3.5	1.9	Noticeable and comfortable
160	2	0.8	3.2	5	2.8	Very noticeable but acceptable in certain high-activity areas if air is warm
200	2.3	1.0	3.7	6	3.3	Upper limit for air-conditioned spaces Good air velocity for natural ventilation in hot and dry climates
400	4.5	2.0	7.2	7	3.9	Good air velocity for comfort ventilation in hot and humid climates
900	10	4.5	16	9	5.0	Considered a gentle breeze when felt outdoors

*The values in this column are the number of degrees that the temperature would have to drop to create the same cooling effect as the given air velocity.

Figure 6 Table of influence of wind speed and thermal comfort

In his book Cooling, Heating, and Lighting (Lechner, 2015), Lechner, shows a table about theair velocities related to thermal comfort. For Indonesia that having hot and humid climates, the recommended air velocity is 2.0 m/s. Air velocity can improve the ACH in the building. The higher the air velocity, the higher also the ACH will be.
Therefore, the assumption for teaching and learning rooms to minimize the transmission of the COVID-19 virus to the occupants is if the passive ventilation system does not produce any air recirculation and the ventilation rate reaches 8 ACH as recommended by WHO and ASHRAE. While for the opening ratio, the standard that will be used in the COVID-19 condition is from the Minister of Health of the Republic of Indonesia Number 829 / MENKES

/ SK / VII / 1999 states that the area of permanent natural ventilation or ventilation is at least 10% of the floor area.

RESEARCH METHOD

This study uses measurement as the primary technique of data collection. The preliminary data include components of independent variables (influenced factors), which include: inlet wind speed, wind direction, room size, opening area, opening position, and opening type. At the same time, the dependent variable in this study is the wind flow pattern and ACH in the room. To determine the effect of the independent variable on the dependent variable in this study, it will go through the simulation stage.

This research will take a studio room in the Mohammad Natsir Building, FCEP UII, as the case study population. The sampling was using purposive sampling. Purposive sampling in question is the selection of a particular space following the purpose of the study. Determination of sampling at STUDIO - IV/3F on the 4th floor of the FCEP building was representative of the studios located on the north wing. The North wing has five typical studio rooms that are used mainly by the architecture student. In this way, it is hoped that the simulation in the studio room can also help evaluate before holding face-to-face lectures amid a pandemic.

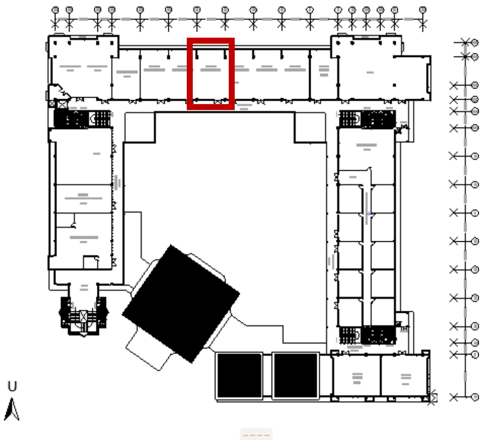


Figure 7 Choosed studio space in the FCEP Building, UII

The first thing to do in the simulation stage is a Microsoft Excel simulation to evaluate the ACH in the room. At this stage, the ACH calculation formula is related, namely:

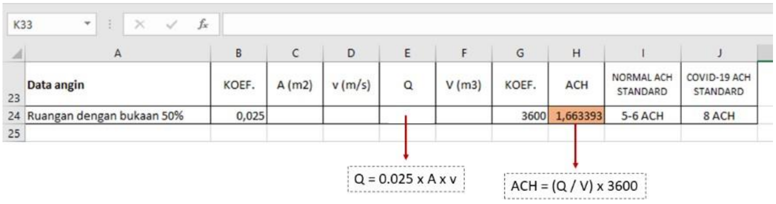
ACH = (Q/V) x 3600…… (1)

Q is the level of natural ventilation (m3/s), and V is the volume of the room (m3). The formula can obtain the level of natural ventilation itself (Q):

Q = 0.025 x A x v .... (2)

A is the opening area (m2), v is the wind speed at the opening (m/s), and 0.025 is the coefficient of times (Erick Christ P.S, p. 2014).

After taking the data, the numbers that have been obtained will be entered into a Microsoft Excel table that has been filled with the ACH formula.



	A	B	C	D	E	F	G	H	I	J
23	Data angin	KOEF.	A (m2)	v (m/s)	Q	V (m3)	KOEF.	ACH	NORMAL ACH STANDARD	COVID-19 ACH STANDARD
24	Ruangan dengan bukaan 50%	0,025					3600	1,663393	5-6 ACH	8 ACH
25										

Figure 8 Data processing techniques in excel

After entering, it can be seen whether the ACH in the studio room has met the standard or not. Then, using the same table, simulations can also be performed simultaneously. By changing the number in column A (opening area) or v (wind speed), the results listed in the ACH column will indicate whether the simulation in that option has met the standard or not.

After simulating in Microsoft Excel, the data also inserted in the Solidworks modeling. Using Solidworks Flow Simulation, the airflow will be physically shown. By the simulation in Solidworks Flow Simulation, we can see the quality of the airflow by the natural ventilation.

RESULTS AND DISCUSSION

The studio classroom was located on the 4th floor north wings of the building. It contains of five typical studios. The profile of the room as follows:

1. Room dimension

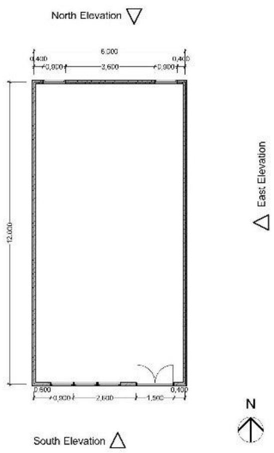


Figure 9 Studio Plan

Room volume: 6m x 12m x 2.8m = 201,6 m^2

2. Opening dimension

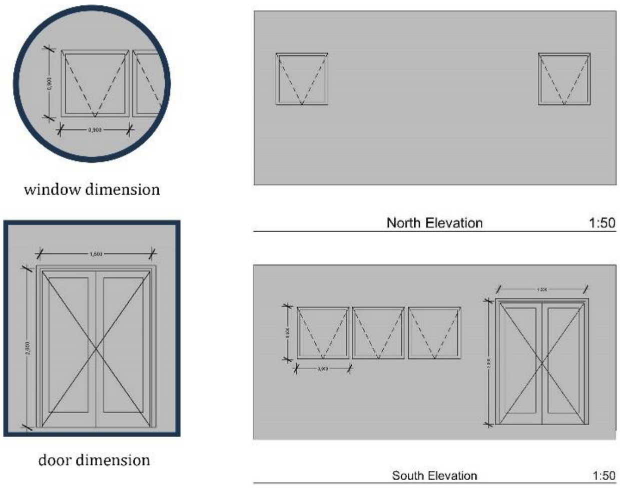


Figure 10 Studio's opening dimension

Window type : top hinged 0,9 x 0,9 m^2 (maximum opening angle at 45^0)
Door profile : Double hinged door 2,1 x 1,5 m^2
Number of window : 5 windows
Total window area : 3,24 m^2

3. Wind speed
   2,3 m/s (according to mean data by anemometer during data collecting)
   2,7 m/s (annual average windspeed according to Meteoblue.com data)

The data was process trough Microsoft Excel was inserting the data above to be processed in the ACH calculation. The wind speed data used is data from Meteoblue.com as a source. The consideration is that the data has been in the form of an average for one year. In the real condition, we can see the results of ACH calculation (1,95 ACH) is below the regular standards.

Table 1 Results of ACH calculation in actual room condition

Real condition with Meteoblue wind data	ACH	NORMAL ACH STANDARD	COVID-19 ACH STANDARD
Real condition (Window total area counted 50% due to its type)	1,95268	5-6 ACH	8 ACH

Dari hasil simulasi menggunakan Solidworks Flow Analysis, didapatkan bahwa ada bagian di dalam ruangan yang tidak dilewati oleh sirkulasi angin (eddy type). Dengan kondisi tersebut, udara yang ada pada bagian tersebut hampir tidak dapat bersikulasi karena udara hanya berputar pada bagian itu saja. Sedangkan pada kondisi pandemi, direkomendasikan untuk adanya pergantian udara dalam keseluruhan ruangan.

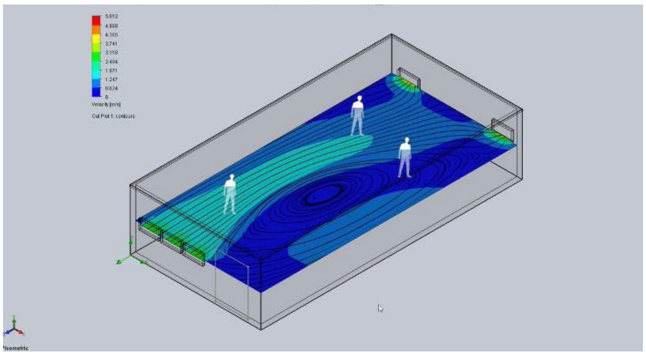


Figure 11 Airflow simulation in actual condition

Based on the factors that affecting the airflow, there are two options that can be considered to reach the standards:

1. Enlarge the opening area
2. Increase the wind speed

The first option is to change the shutters to casements that can be fully opened so that the wind will enter completely. That way, the total opening area can reach a maximum (3.24 m2). It turns out that changing the shutters can increase the room's air circulation to 3.90 ACH. However, this value is still not enough to reach the regular standard though.

Table 2 Results of ACH calculation in Option 1 room condition

Option 1	ACH	NORMAL ACH STANDARD	COVID-19 ACH STANDARD
Real condition with changing the window leaf to maximum opening 90^0 angle (fully open)	3,90536	5-6 ACH	9 ACH

From the results of Solidworks Flow Simulation, the results are not much different from the actual conditions. It's just that the part that has less eddy-type wind circulation than the original condition. In addition, the wind speed circulating in the room is greater so that the air can be changed more often than the actual condition.

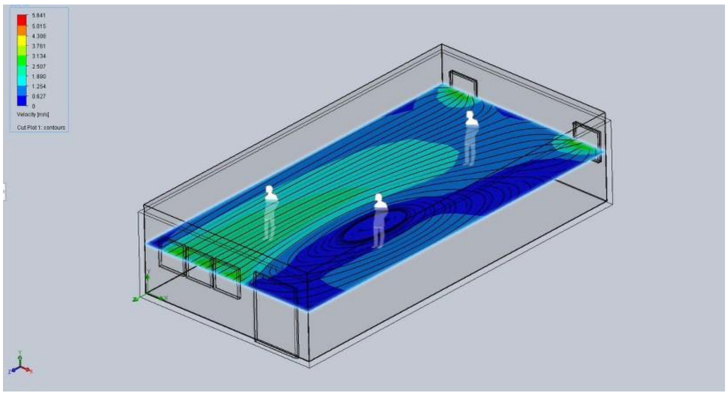


Figure 12 Airflow simulation in Option 1 condition

The second option is to increase the wind speed. In this simulation, it can be seen that the wind required to reach the ACH standard in general for lecture rooms with a constant physical condition of the room is 7m/s. Meanwhile, to reach the standard recommended during the COVID-19 pandemic, 11.1 m/s is needed. However, as in Lechner's book, winds with speeds above 5m/s are no longer considered comfortable wind speeds. In addition, to increase the wind speed from 2.7m/s to 7m/s requires considerable effort but is not effective to be applied in buildings.

Table 3 Results of ACH calculation in Option 2 room condition

Option 2	ACH	NORMAL ACH STANDARD	COVID-19 ACH STANDARD
Increase air velocity to 7m/s	5,0625	5-6 ACH	8 ACH
Increase air velocity to 11,1 m/s	8,02768	5-6 ACH	8 ACH

From the simulation results, it can be seen that the wind speed of 11.1 m/s that enters the room even though it can reach 8 ACH, but produces wind that is not comfortable for activities. The majority of the wind is above 5 m/s where the wind with that speed is more

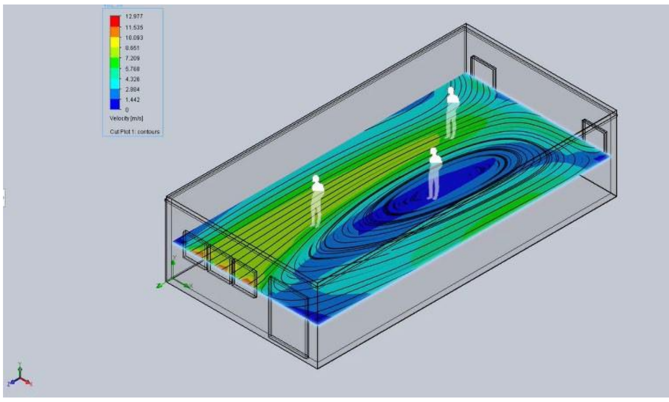


Figure 13 Airflow simulation in Option 2 condition

suitable for outdoor activities (Lechner, 2015)

Because the previous option still can't reach the standard, the next option is to expand the total instead. This can be achieved by expanding the dimensions of the window and making use of the type of opening. By expanding the non-minimum to 4.2m2, the ACH will reach the regular standard of 5 ACH. Meanwhile, by expanding the opening up to 6.7m2, ACH will reach the minimum standard recommended in the conditions of the COVID-19 pandemic.

Table 4 Results of ACH calculation in Option 3 room condition

Option 3	ACH	NORMAL ACH STANDARD	COVID-19 ACH STANDARD
Enlarge the opening area to total 4,2 m2	5,0625	5-6 ACH	8 ACH
Enlarge the opening to 6,7 m2	8,07589	5-6 ACH	8 ACH

Keeping the room's default state, another option to increase the ACH is to replace the shutters so they can be fully opened by 900 and make the door an opening on condition that both leaves are fully opened. This is proven to make air circulation to 7.7 ACH. This figure is already above the general standard, and is only 0.3 points below the recommended ACH for pandemics.

Table 5 Results of ACH calculation in Option 4 room condition

Option 4	ACH	NORMAL ACH STANDARD	COVID-19 ACH STANDARD
Change the window leaf (fully open) and make door as opening also (1,5 m x 2,1 m)	7,70223	5-6 ACH	8 ACH

The simulation results in Option 4 show that the wind flow is almost in line with what is recommended. At the average human height, there is no visible eddy wind flow, so the air in the entire room can circulate and be replaced with new air. The air speed is also in a range that is quite comfortable for indoor activities.

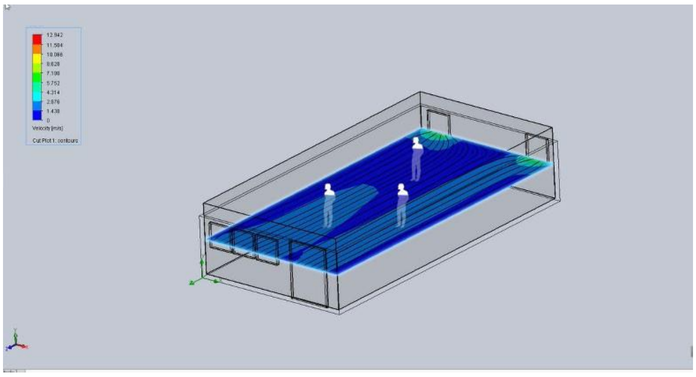


Figure 14 Airflow simulation in Option 4 condition

After knowing Option 4, then the possible effort beyond increasing wind speed, is to expand the window. From the calculations in the simulation, the addition of a window area of 0.27m2, can produce ACH which is in accordance with the recommendation, namely 8 ACH.

Table 6 Results of ACH calculation in Option 5 room condition

Option 5	ACH	NORMAL ACH STANDARD	COVID-19 ACH STANDARD
Enlarge the window to (0, m x 0,9 m), change the window leaf (casement, fully open) and make door as opening also (1,5 m x 2,1 m)	8,02768	5-6 ACH	8 ACH

Conclusion and Recommendation

From this research, it can be concluded that the current condition of the studio room is not safe enough as a place for face-to-face lectures in the conditions of the COVID-19 pandemic. This is because the studio room ACH is still far below the ACH recommendation under normal conditions. The value is 1.95 ACH from 5 ACH under normal conditions, and 8 ACH during a pandemic. In addition, not all parts of the room can be reached by wind circulation so that the air in the room in that section cannot be replaced.

Of the several design options, the closest to the recommendation is Option 4, which is to change the shutters to a casement type and make the door an inlet. Option 4 has an ACH that is close to the recommendation in a pandemic condition where the value is 7.7 ACH out of 8 ACH. In addition, it has an even wind circulation and a fairly comfortable speed. That way, the air in the room can be replaced properly.

To achieve a full 8 ACH, the recommendation is to increase the opening area by expanding the window by at least 0.27m2. The addition of the window area can be applied to the inlet window so that more percentage of the wind enters the room.

In the future research, this topic will be more interesting to include human respiration flow as one of the variable. It may give more precise simulation with the real life and precise recommendation in order to create more healthy building in the future.

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