Natural Ventilation Optimization Study in Mechanically Ventilated Studio Apartment Room in Surabaya

by Elvina Wijaya

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After Covid-19, residential has become the main space for every activity, including work, education, and leisure. Therefore, comfort in residential space is crucial to the occupant. As researchers have found traces, that the virus is airborne, the air quality in the residence must be highlighted, especially for people who live in a centralized cooling system residence. When the cooling system is well maintained, there is no significant risk of viral transmission, but not all residential building has HEPA-filters, nor a well-maintained system. This research focuses on the studio room apartment unit, as it has the smallest opening area compared to other room types. A small one-sided opening is not ideal for the wind to move throughout the room. A few design suggestion is simulated under three air-flow speed, to prove that natural ventilation is possible to be adapted, to reach comfort while minimizing the risk of viral transmission. The result is, the indoor wind speed can be enhanced the most at the overall unit area by modifying the fixed window to an operable window, giving upper horizontal opening in the wall across the existing opening, and using gauze doors on both door openings. The furniture layout is proved to affect wind distribution in the room. This research can also serve as an alternative strategy to optimize the use of natural ventilation to decrease energy use for cooling in the tropic area, after the pandemic.

Keywords: Design adaptation; Indoor airflow; Viral transmission

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1. Introduction

The rapid spread of Covid-19 has shocked the world. The impact of the pandemic is massive and involves many aspects of living. From the architectural design perspective, covid-19 has reminded us, that the design should be adaptable and resilient, even to unplanned change in a short period time. As it is easily spread between an infected people to another person around him, one of the effective ways to protect ourselves is to stay at home. This policy makes the residential area the main, if not only, place of all activity that used to takes place outside. People now are working from home. Home is also a classroom and playroom for students who are taking the class online. The use of the residential area is now more than just a place to rest and retreat.

Although the action was taken for safety concern, there have been reports of increasing mental health problems, due to isolation during the pandemic, ranging from mild stress to anxiety disorder [1, 2], that makes the online mental health service increase too [3]. A suggestion to overcome the mental health problem is to do more physical activity, which activates the muscular system, so that the immune system can be boosted too [4]. This suggestion adds more function to a mere residential area. Therefore, it should be reassured that the condition of the residential area gives the occupants a healthy impact: safety from the viral transmission and comfortable.

Indoor air quality has a significant role in achieving comfort, but during this pandemic, a special concern is given to the quality of air. It has been found that the virus is rapidly multiplying in the condition where the day and night temperature has a great difference. That makes the cold and dry climate, an ideal region. But the research also concluded that it is naive to rely solely on the warmer climate condition [5]. Another research also found the HVAC system is suspected to be transmitting the virus, as not specially equipped for infectious diseases, though the data is not sufficient to make a steady conclusion that the virus is airborne [6]. HEPA filters can filter unwanted particles, with the size as small as 0.3 μm. The coronavirus itself has a size of 0.004 to 1 μm, but is usually found compounded in other larger particle elements, such as water or droplets from an infected person, and rarely found as virus particles only. This makes coronavirus spread, with the size around 0.25 to 0.5 μm [7]. That is why the use of HEPA filters are still effective to break the viral transmission. But not all mechanically ventilated residential use this kind of filter. Design strategies to prevent the viral transmission mainly mention natural ventilation, increased ventilation rate – air change per hour, and fresh air supply, besides the use of air cleaners and the act to avoid over-crowded areas [8].

When the residential area is spacious enough to do more activity, to place more openings to support natural ventilation, sure there will be fewer problem. The purpose of this research is to assess, whether the natural ventilation principle is possible to be adapted, in a less optimal residential areas, such as an apartment.

2. Method

2.1. Unit description

This research focusses on a studio apartment room, located in South Surabaya, around 6 kilometers far from the Juanda BMKG Meteorological Office. As the apartment sited near the university campus, the main dweller in this apartment is, but not limited to, students from the campus. Here, we choose a studio room that facing North, as the wind in Surabaya mainly blows in East-West direction, with the speed of 3.74 m/s on average [9]. Table 1 shows Surabaya's wind database for 30 years, showing the sum of days within a month with a certain wind speed, and also the recorded wind direction, with the result that is similar to the data from Surabaya's weather station.

From the data obtained, we can conclude that the condition of measurement will not be ideal for the natural ventilation to happen: a small one-sided opening, which not facing the wind directly. The unit has a 30 m^2 area and is located on the 17th floor, so the wind movement will not be obstructed. Besides the main door, room openings are one-sided, which are fixed windows (1.825x2.6 m) and a door to the balcony (0.8x2.2 m). The situation of the unit can be summarized in Table 2.

The initial measurement took place on September 26-28th, 2020. The data collected is the wind-speed and the difference in indoor–outdoor temperature. These variables are needed for the simulation. The initial measurement is done under two conditions:

a. Day 1: With both doors are closed all day, and the air conditioning system is turned on. HOBOs are placed as in the table above. The anemometer wind vane was placed in +1.5 m, and stayed on at the balcony during the measurement. The maximum, minimum, and average wind-speed is then collected per hour. The indoor wind speed is measured by hand anemometer at the height of +1.5 m, beside the indoor HOBO. This stage was done to prove that the indoor wind-speed when the air conditioner system turned on was zero all day.

b. Day 2: With opened door to the balcony, and the main door to the corridor was closed. The air conditioning system is turned off. HOBOs are placed as in the Table 2 above. The anemometer wind vane is placed in +1.5 m, and stayed on during the measurement. The maximum, minimum, and average wind-speed is then collected per hour. For more detailed result, the indoor wind-speed is then simulated using Ecotect Analysis 2011- Winair4 (CFD)

2.2. Natural Ventilation Strategies

Certain strategies that can be done to maximize the flow of natural ventilation that can be summarized as two main strategies. The first is to place the opening on two sides of the room. In one-sided opening, the inlet and outlet of the wind is the same opening, therefore, one-sided opening is effective, only when the depth of plan is smaller than the ceiling height multiplied by 2.5 [11]. Giving opening on the different side of the wall may change the wind movement in the room. The placement of the opening should be designed, so that the wind passes the human activity area.

Another research has concluded, that the furniture layout has a significant role in spreading the air in the room, to maximize comfort [12, 13]. Therefore, in this research, the difference in furniture layout is also being implemented in the simulation.

The second important concern is the dimension of the inlet-outlet opening in cross ventilation. The condition is preferable when the outlet opening is, at least, 25% bigger than the inlet, because it can enhance both the ventilation rate and wind-speed [11]. Changing types of window can enhance the performance of natural ventilation, as the existing windows are fixed windows that have no contribution to airflow.

The adaptation target is to maximize the area that has

Table 1. Total day count with a certain wind speed and direction database for Surabaya [10]

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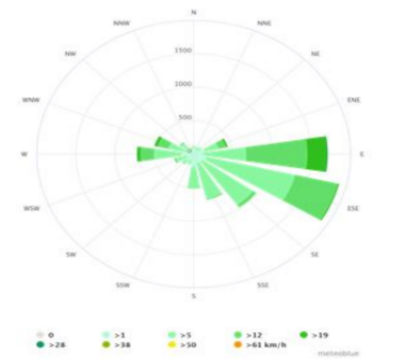
<td>height 
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<td>Total day – Wind Speed (km/h)</td>
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comfortable wind-speed, which is 0.25-0.5 m/s. Below 0.25 m/s to 0,1 m/s, the wind is still found comfortable, yet no movement can be sensed. It also has no effect to thermal cooling. From 0.5-1 m/s, the wind is still comfortable, and the wind movement can be sense briefly. Above 1.5 m/s, the wind-speed can be disturbing for the resident [14]. Besides how to make the air flows well, the purpose of good cross ventilation is also to reach the standard of the air change per hour in a residential area, to make sure the occupants are surrounded by a sufficient amount of fresh air. The ACH standard for family and bedroom in the tropic area is 20 times per hour [14]. Indonesian National Standard for Building Ventilation also set the minimum ACH rate of 6 for living spaces, and 20 for kitchen [15]. During the pandemic, ACH rate has been increased within the range of 6 to 12 or more per hour, where 6 times is commonly used in offices and classrooms, and 12 times or more, when we want to clean the air in the room as in the hospital, to prevent the spread of tubercolosis [16]. Another source has calculated, to be able to minimize the time for the contaminated air to be fully replaced with the fresh air, there will be 50 times of air changes per hour needed [17]

2.3. Simulation Strategies

The studio room is directly connected to the corridor without any buffer area. So, giving an opening to the corridor can be a threat to occupant's privacy. Therefore, the opening to the corridor in this simulation is designed as a clerestory above the pantry cabinet, which surpasses the human eye level. The simulation also uses a gauze door as a second layer to the main and balcony door, to protect occupant's privacy, and wind inlet-outlet at the same time. In the existing condition, the wardrobe position is in the middle of the room, which assumes that it may block the airflow to the dining area. Therefore, the mirrored layout is also simulated as plan b in this research, as seen in Fig. 1a and b.

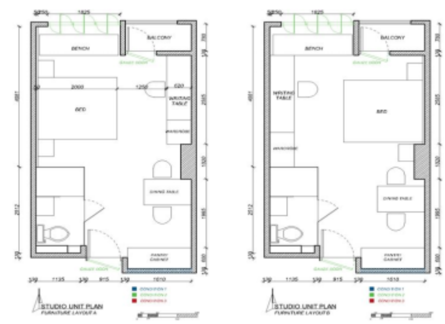


Figure 1a. The original layout and the scenarios **Figure 1b.** The mirrored layout and the scenarios

Fig. 1. Condition for Simulation.

The four conditions of simulation can be listed as below:

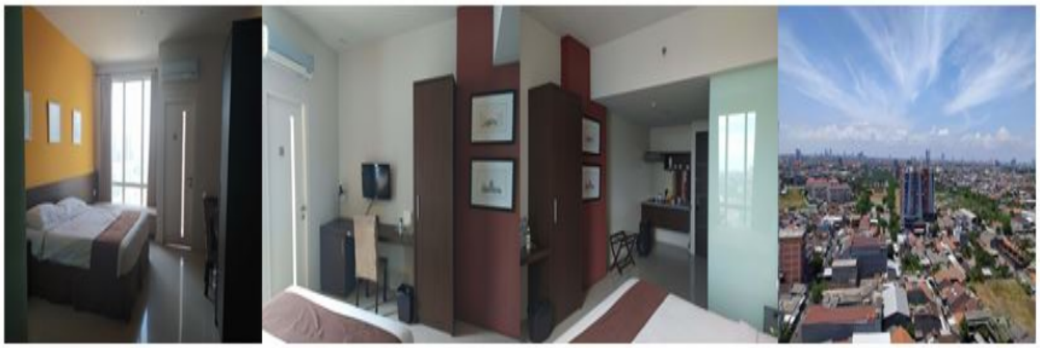
a. Simulating the existing condition (condition 0): Simulation of air-flow when only the balcony door is opened, and also both doors (main and balcony) are opened. The furniture is also simulated as the original arrangement.

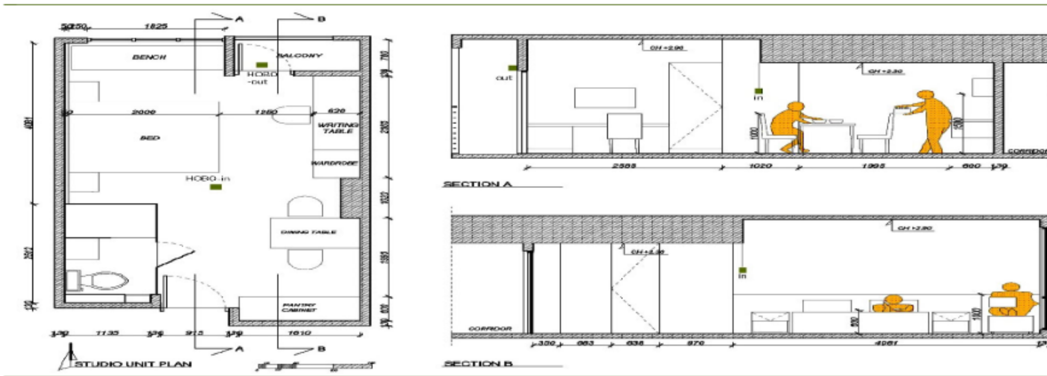
b. Simulation, when the main door is closed, and the balcony door is opened. In this stage, the fixed windows are replaced with pivot windows, in the upper segment of the windows. This stage is also simulated in two different furniture layout (condition 1a and b)

c. Simulation, when the two doors are opened, and gauze doors are applied. The fixed windows are replaced with pivot windows, in the upper segment of the windows.

Table 2. Studio Room Data.

Outdoor Temperature (°C)	Min: 26.5 °C
	Max: 36,9°C
Indoor Temperature (°C)	Min: 26.3°C
	Max: 32,3°C
Wind Speed	Min 0,0 m/s; Max 1.9 m/s; Average 0,583 ⟵ 0,6 m/s





This stage is also simulated in two different furniture layout (condition 2a and b)

d. Simulation, when the two doors are opened, and gauze doors are applied. The existing fixed windows are still used in this simulation. This stage is also simulated in two different furniture layout (condition 3a and b)

As described above, the designed cross-ventilation should pass the human activity area. In this pandemic, this studio apartment is not only a place to rest but also another activity. Therefore, in the simulation, the airflow is plotted in three heights: +0.6 m (for rest activity), +1.0 m (for sit activity), and +1.5 m (for stand activity). The average and maximum outdoor wind speed from measurement are simulated, altogether with the annual average wind-speed from the BMKG Juanda. So, this simulation also uses three wind-speed (0,6 m/s, 1.9 m/s and 3.74 m/s)

3. Finding and Discussion

3.1. Simulation Result

The simulation is using Ecotect Analysis 2011, with Winair4 CFD. The 3D model is drawn for each condition in Autocad, then exported in dxf format. Input for this simulation is wind speed, wind direction, and indoor-outdoor temperature. As the airflow found in the simulation does not exceed 0.8m/s in all conditions, the upper limit of the scale is then degraded to 0.8 m/s to achieve a more vivid colour scale. The result of the simulations are:

a. Condition 0, as seen in Fig. 2:

• When simulated using 0.6 m/s and 1.9 m/s, the overall airflow is stagnant in range 0-0.16 m/s in all heights of measurement. Higher airflow can be found in the lower height of the room.

• When simulated using average wind speed data, the centre area of the room has 0.24-0.40 m/s airflow speed in the height of rest as both the main door and balcony door are opened. In the condition, where the main door is closed, the room has only 0-0.16 m/s airflow. The speed in both condition, at height of +1 m and +1.5 m decrease to 0.16-0 m/s. The condition where both doors are open is better than the main door is closed

b. Condition 1, as seen in Fig. 3:

• When simulated using 0.6 m/s, the overall airflow is stagnant in range 0-0.16 m/s in all heights of measurement for both plans. Plan b shows that in the rest activity height, the wind hits the bed and then having slower speed, but the larger area.

• When simulated using 1.9 m/s, the wind at +0.6 m can infiltrate the room further in plan a. In plan B, as it hits the bed, the speed is lower, but the area and distribution are larger. The speed ranged from 0.24-0.40 m/s in both plans. In the height of +1 m and +1.5 m, the airflow speeds are reduced. The overall plan has 0-0.16 m/s, except in the balcony door area.

• When simulated using average windspeed data, both plans show infiltration by the wind, which has 0.24-0.48 m/s airflow speed. The patterns though are different. In plan a, the airflow in +0.6 m are concentrated in the middle of the room and then spread as the height increases, to the perimeter of the plan. The speeds are reduced too. In plan b, the wind infiltrates the room further. The 0.24-0.4 m/s airflow hits the pantry wall at the height of +0.6 m and +1 m. The speed decreases in +1500 to 0.16-0.24 m/s. From the section, we find, that the position of the bed blocks the wind, and makes the wind goes in the activity area (rest and sit), while in plan a, the comfortable wind speed stays below activity area.

c. Condition 2, as seen in Fig. 4:

• When simulated using 0.6 m/s, the overall airflow is stagnant in range 0-0.16 m/s in all heights of measurement for plan a. Plan b shows that in the rest activity area, at rest height, the airflow is somehow comfortable, at 0.16-0.24 m/s.

• When simulated using 1.9 m/s, the wind at +0.6 m can infiltrate the room further in plan a and b. Plan b has a higher range of speed, between 0.24-0.40 m/s while in plan a, the range is between 0.16-0.24 m/s. In the height of +1 m, plan b still shows the same airflow speed, while in plan a, the speed is already decreasing. Both of the plans show stagnant speed in 0-0.16 m/s in +1.5 m.

• When simulated using average windspeed data, both plans show great infiltration by the wind. In plan a, the airflow speed ranges from 0.24-0.40 m/s, and forms an area like a thick line, connecting the balcony and the main door, especially in the height of +0.6 and +1 m. In +1.5 m, the wind slows down to 0.16 m/s, and form thinner line in the right side of the plan. In plan b, the wind blows faster at range 0.24-0.56 m/s and spread throughout the room at all activity height. At the height of +1.5 m, the airflow speed around the dining and pantry area is still 0.32-0.24 m/s. This makes this scenario the most ideal natural ventilation simulated.

d. Condition 3, as seen in Fig. 5:

• When simulated using 0.6 m/s and 1.9 m/s, the overall airflow is stagnant in range 0-0.16 m/s in all heights of measurement. Higher airflow can be found in the lower height of the room.

• When simulated using average windspeed data, plan a and b show a decrease in airflow speed. The airflow in plan a range from 0-0.32 m/s and goes slower as the height rises. In plan b, the speed is even slower, between 0-0.24 m/s, but scattered in the perimeter of the room, especially in dining and pantry area.

The airflow speed range and percentage of the comfortable area can be seen in Table 3, as a summary from the simulation graphic. We can see that the scenarios that have airflow in comfortable speed are scenario 1a, 1b, 2a, and 2b. As the wind speed increases, so does the comfortable speed area.

3.2. Discussion

Of the 24 simulations done in this research, some conditions have brought the wind with the airflow ranged in preferable speed for comfort. Simulation using 3.74 m/s speed is the most optimal in nearly every condition simulated. But considering that the speed is average data from the meteorological station, even though located relatively near to the apartment, the condition that makes the wind has such speed is not found at the apartment surrounding, at the days of measurement. That is why, for air change per hour, only the conditions with the speed of 1.9 m/s are calculated. These are conditions 1a and b, also conditions 2a and b.

When the outdoor wind speed is 1.9 m/s, the opening of the unit, which are operable pivot window and balcony door, will give a total ventilation rate of 30.506,76 m3 per hour. The total room volume is 78 m^3. Therefore, the air change per hour is 391,11 times. It exceeds the standard of

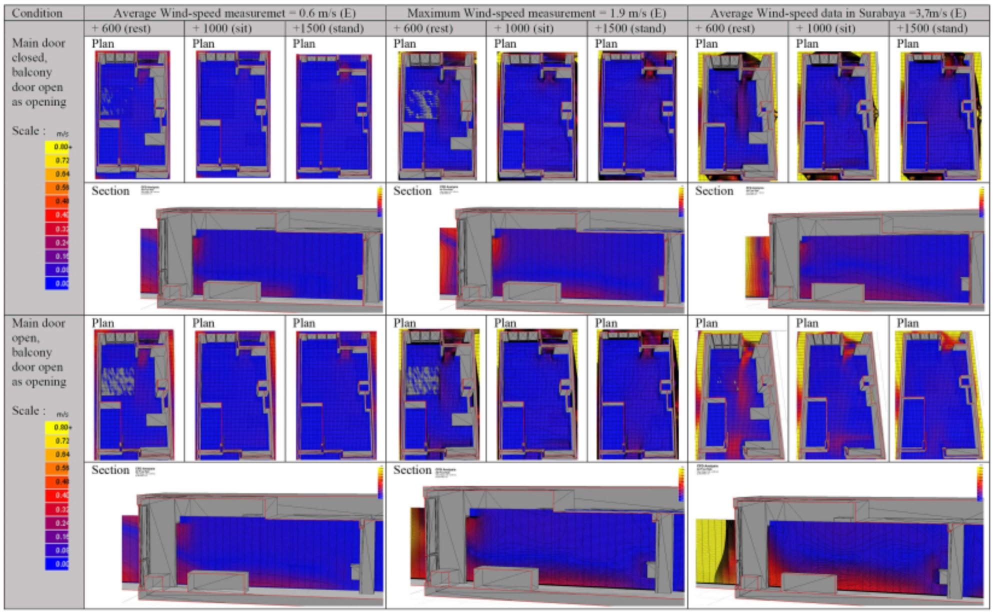


Fig. 2. Condition 0.

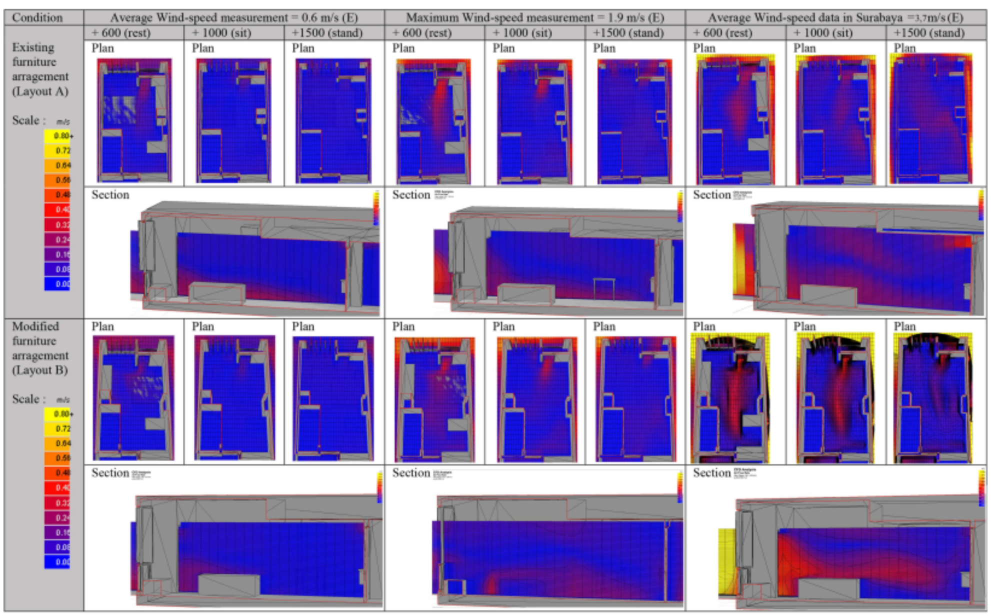


Fig. 3. Condition 1a and b: Changing Existing Window to Operable Pivot Window and Adding Opening Above The Pantry.

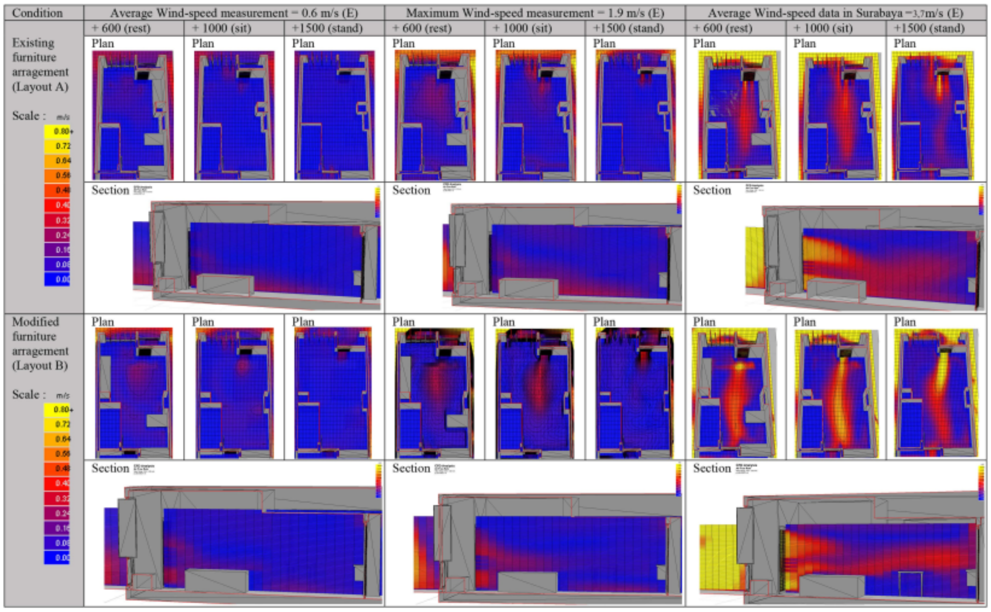


Fig. 4. Condition 2a and b: Changing Existing Window to Operable Pivot Window, Adding Opening Above The Pantry, and Using Gauze Doors.

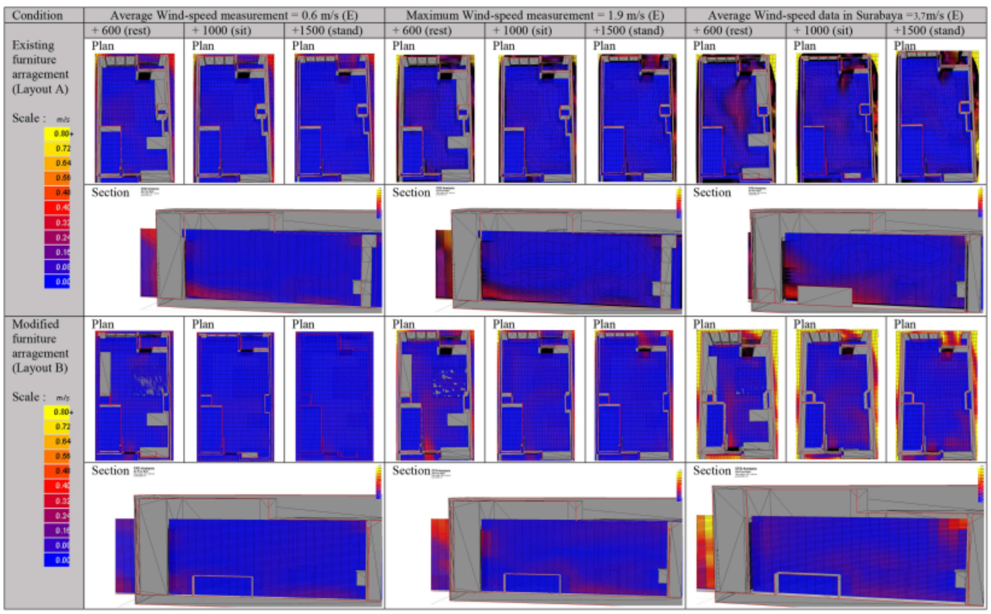
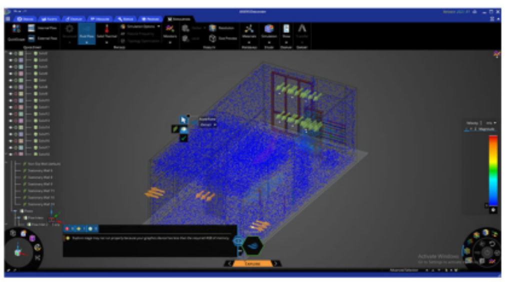


Fig. 5. Condition 3a and b: Change Back The Pivot Window To Fixed Window.

Table 3. Air flow speed and Area Summary from Simulation Graphic.

				0.6 m/s East (average)			1.9 m/s East (max)			3.7 m/s East (avg. Sby)		
				+0.6m	+1.2m	+1.5m	+0.6m	+1.2m	+1.5m	+0.6m	+1.2m	+1.5m
S0	.0	Air flow	m/s	0-0.16	0-0.08	0-0.16	0-0.16	0-0.16	0-0.16	0-0.16	0-0.16	0-0.16
		Area	%	0	0	0	0	0	0	0	0	0
	.1	Air flow	m/s	0-0.16	0-0.16	0-0.16	0-0.16	0-0.16	0-0.16	0-0.40	0-0.16	0-0.16
		Area	%	0	0	0	0	0	0	25	0	0
S1	A	Air flow	m/s	0-0.24	0-0.16	0-0.16	0-0.40	0-0.40	0-0.16	0-0.32	0-0.32	0-0.32
		Area	%	5	0	0	15	5	0	20	15	15
	B	Air flow	m/s	0-0.24	0-0.08	0-0.08	0-0.40	0-0.32	0-0.24	0-0.40	0-0.40	0-0.32
		Area	%	8	0	0	15	5	5	40	35	10
S2	A	Air flow	m/s	0-0.24	0-0.16	0-0.08	0-0.24	0-0.32	0-0.32	0-0.64	0-0.64	0-0.64
		Area	%	5	0	0	15	5	2	30	35	10
	B	Air flow	m/s	0-0.24	0-0.24	0-0.24	0-0.32	0-0.32	0-0.32	0-0.64	0-0.64	0-0.72
		Area	%	10	5	2	15	20	5	40	40	30
S3	A	Air flow	m/s	0-0.08	0-0.08	0-0.08	0-0.16	0-0.16	0-0.16	0-0.16	0-0.16	0-0.16
		Area	%	0	0	0	0	0	0	0	0	0
	B	Air flow	m/s	0-0.16	0-0.08	0-0.08	0-0.32	0-0.16	0-0.16	0-0.32	0-0.24	0-0.24
		Area	%	0	0	0	2	0	0	2	2	2



0,6m/s East (average), Scenario 2A

Speed (m/s)	+0,6 m	+1,2 m	+1,5 m
ANSYS	0- 0.2	0-0.2	0
Ecotect	0-0.24	0-0.16	0-0.08

Fig. 6. Simulation using ANSYS Discovery 2021 and Comparation to Ecotect Result.

air change per hour in the tropics area, which is 20 times per hour, for the living room and bedroom. The standard stated that in the cooking area, the air change per hour needed is 100 times per hour, so the condition has met the requirement also.

When we remove the modified pivot area, the ventilation rate drops to 10.533,11 m^3 per hour, and the air change per hour found is still 135,04 times per hour, and still meets the healthy standard. This is what will happen when we apply scenario 0.0, but the airflow speed will be stagnant, as simulated.

If the outdoor wind speed used for the calculation is 0.6 m/s, the air change per hour is also decreased to 129,6 times per hour, as the ventilation rate is also decreased to 10.108,98 m^3 per hour. This condition also fulfills the requirement for healthy air change per hour. Based on the calculation, when the 0.6 m/s wind speed is applied, opening only the balcony door makes the air change per hour decreases to 48,7 times. This rate does not meet the criteria in the cooking area, but the existing pantry has already had a cooker hood to help trap the unwanted particles in the air. But still, the indoor air might feel stagnant. This simulation and calculation prove that natural ventilation can be applied in a studio apartment room, by doing modification as stated.

From the section of the simulation, we find that the furniture arrangement in plan b is more optimized to spread the airflow throughout the room, as it directs the airflow to the human activity area and has a larger distribution area with comfortable airflow speed in every simulated human activity height.

Wind simulation using CFD is usually done together with a scaled model wind tunnel experiment as a validation method. Due to the limited time and lack of simulation tools, the real wind tunnel experiment with real model is not implemented in this research. Therefore, another simulation using another CFD simulation software, ANSYS Discovery 2021 is done as a comparation to the simulation using Autodesk Ecotect. The second scenario is chosen for being simulated, as that is the scenario with the most optimised wind speed is simulated. The simulation is using 0.6 m/s windspeed in unit's inlet. The green arrows are the defined inlets, and the orange arrows are the outlets. The result is that the wind blows at nearly the same speed when simulated using the two simulation softwares as below. Therefore the wind speed data from the simulation can be seen as a valid data.

4. Conclusions

From this research, it can be concluded that the adaptation of natural ventilation in a mechanically ventilated designed room, especially an apartment with studio type, is possible. There are two considerations for optimizing the use of natural ventilation, which are the airflow speed and the air change per hour. The modification done in condition 1 and 2, simulated in this research has met the standard in both plans. The plan b generally can spread the airflow better than plan a, where the airflow is concentrated in the middle of unit.

Little modification, like turning off the HVAC system, then opening the balcony door is proved to be sufficient to achieve the needed ACH. To gain more comfort needed from wind movement when doing physical activity, such as yoga or light stretching, more adaptation is needed. In this paper, the modification simulated is by changing the type of the window, from fixed to pivot window and an adding opening above the pantry cabinet. The use of the gauze door is also simulated altogether with the pivot window and clerestory. When the pandemic is over, this conclusion can also serve as a design strategy input for more optimized natural ventilation use in an apartment unit. For future improvement, wind tunnel experiment should be held as a more valid method of validation.

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