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Infectious Inpatient Hospital Ward Air Ventilation System Design. Learning From the Covid-19 Pandemic Case Study: Budi Kemuliaan Hospital, Batam Island, Indonesia

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Abstract: *Learning from the COVID-19 pandemic that hit Indonesia and all over the world, hospitals' requirements and standards have changed. The most critical requirement for inpatient rooms is the air ventilation, since COVID-19 and airborne virus spreads through droplets and airflow. This study examines the placement of the intake and exhaust air supply as well as the placement of patient beds in the safest inpatient rooms for patients, nurses, and doctors. This study compared the ventilation performance of several intake–exhaust layout scenarios in the inpatient room of Budi Kemuliaan Hospital, Batam Island. Airflow simulation was carried out quantitatively using the Ansys simulation tool. From the four existing scenarios, the scenario with AC as inlet and exhaust as outlet (full mechanical ventilation) is the best. The AC supplies a stable and adjustable air flow, as does the exhaust fan, which can stably draw dirty air. The benefits of this study are expected to be an input for better air ventilation requirements and architectural standards for inpatient rooms at hospitals for types of airborne diseases and infectious departments.*
Keywords: *hospital design; inpatient ward; indoor air ventilations; COVID-19*

1. INTRODUCTION

Indonesia is one of the countries experiencing the COVID-19 pandemic. The pandemic began in early 2020 and had an impact on changes to the work system of service activities, including changes to building standards, facilities, and equipment in hospitals (Minister of Health, Republic of Indonesia, 2016; 2020; 2022; Tim Pokja Kemenkes, 2020) [1,2,3,4]. Considering that the COVID-19 virus can spread through the air or airborne, it is important to understand this principle within the hospital complex while maintaining comfort for patients, nurses, and doctors who work in the hospital (Secretariat, 2005) [5].

Some of the design principles and standards that have changed include changes to the zoning system, circulation system, spatial relationship pattern system, as well as ventilation and air circulation systems (Awbi, 2003) [6], both natural and mechanical, in hospitals. The principles of air circulation and ventilation in the hospital area play an important role, especially in inpatient rooms where patients can be treated for long periods of time (Atkinson, 2009) [7]. After Covid-19 has passed, this experience can be utilized and applied in hospital design to overcome similar diseases that spread through the air and to improve the quality of hospital medical hygiene (Executive Board of the Indonesian Doctors Association, 2020) [8] and Layout and Ventilation on Inpatient Installation (TPPKKR Indonesia, 2020) [9].

In hospitals that serve the entire community with various layers of economic capacity, for efficiency and to reduce costs, inpatient rooms are filled with more than 1 patient. With limitations and conditions that are not ideal, this research aims to create a simulation of air ventilation from existing conditions to find out what equipment factors have an influence on air flow in the inpatient room. The research case was carried out at Budi Kemuliaan Hospital on Batam Island, Riau Islands Province. Batam Island has a climate with quite hot temperatures, so apart from considering air flow, comfortable temperatures also need to be maintained.

The COVID-19 virus can be transmitted by inhalation of microscopic droplets at short to medium range and can remain in the air for hours (Asadi et al., 2020) [10]. The aerodynamic characteristics and transmission pathways of COVID-19 in aerosol (Liu et al., 2020) [11]. Aerosol transmission of COVID-19 remains infectious and feasible in aerosols for hours and on surfaces for days (van Doremalen et al., 2020) [12]. This research will simulate and investigate some scenarios for combining mechanical ventilation (MV), such as an Air conditioning unit (AC) and exhaust fan, with the arrangement of opening a window as natural ventilation (NV). The previous research indicates that the strategies of natural ventilation are based on the differences in pressure between envelope openings and with indoor room. The difference in pressure is caused by winds, differences between indoor and outdoor temperatures, and both in combination. Therefore, these combinations can be classified as wind-induced and buoyancy-induced ventilation (Wood & Salib, 2003) [13].

Previous research has examined the strategies of natural ventilation based on difference pressure between envelope openings with indoor room that caused by winds, differences between indoor and outdoor temperature, and both of combination, classifying wind-induced and buoyancy-induced ventilation (Wood & Salib, 2003) [13], providing in numerical study on exhaust grilles in close proximity to each patient's bed to prevent and control infection in Middle East Respiratory Syndrome Coronavirus -MERS-CoV (Satheesan et al., 2020) [14], reducing the risk of cross-infection caused through in optimal ventilation parameters; location of the infected patient, air change rate, flow rate of local exhaust, location and size of supply air diffuser using CFD simulations (Satheesan et al., 2024) [15]. Conversely, little is known about the hybrid combination between mechanical ventilation (MV), such as an Air Condition Unit (AC) and an Exhaust Fan with an arrangement opening of a Window as natural ventilation (NV). Previous research conducted in Indonesia showed that the plan of the inpatient room and the position of the inlet and outlet had an effect on improving air circulation (Kartidjo et al, 2021; 2022) [16, 17]. Therefore, this study simulates and investigates some practical and potential scenarios to reduce transmission and enhance indoor air quality in an inpatient hospital ward in a tropical country, especially Indonesia.

The core principle of negative pressure rooms is controlling the contamination from Coronavirus disease (COVID-19). It is an important part of a healthcare facility, especially in a hospital setting (Medical Advisory Secretariat, 2005) [5], to ensure the airflow from a clean area into a contaminated area by COVID-19. This prevents the spread of infectious contaminants area and maintains sterility from coronavirus disease in the inpatient hospital ward through the air ventilation system. According to this principle, the air in a hospital building should flow from the corridors into the liminal spaces, then towards the isolated rooms to prevent the spread of airborne infection isolation rooms (Sammy Al-Benna, 2020) [18] through the air ventilation system. The liminal area is designed to restrict and avoid the contaminated air between contaminating patients, staff, and visitors. The principal basis of controlling the contamination from Coronavirus disease (COVID-19) is negative-pressure rooms. It is an important part of a healthcare facility, especially in a hospital setting (Medical Advisory Secretariat, 2005) [5], to ensure the airflow from a clean area into a contaminated area by COVID-19. In these conditions virus will not flow out of the room.

Negative pressure rooms in the isolated inpatient hospital ward are kept, and air pressure in a room is maintained by the main air supply from air conditioning (AC) and/or windows and exhaust fan. These settings isolate patients with infectious conditions and protect people outside the room from exposure (Sammy Al-Benna, 2020) [18]. And keep its air inside the room with controlled venting only (Y Li et al., 2007) [19].

Meanwhile, the side of the adjacent isolation room that is outside or open air will function as the ventilated windows in maintaining the air pressure in the isolation room negatively. As a result, the area with a negative air pressure could be controlled by the amount of air supply (intake) must be smaller than the air out (exhaust) or vice versa. Therefore, this research will aim to investigate the hospital Scenarios to accomplish the isolation room standardisation, and the implementation constraints for multi-patient wards. It is hoped that the results of this research can be used as input for the preparation of hospital design regulations and standards.

METHOD

2.1 The computational fluid dynamics (CFD) simulation

The computational fluid dynamics (CFD) simulation is performed using Ansys Fluent Student version 2024 in order to numerically illustrate the airflow that is commonly employed to predict the air distribution flow within a building (Satheesan et al., 2020) [14].

This method was developed to analyse natural ventilation (NV) flow behaviour (Ghasempourabadi et al., 2021; Heiselberg and Bjorn, 2002) [20, 21] within the inpatient hospital wards, and the accuracy of these numerical simulations was confirmed against data from literature findings with experiment data (Tominaga & Blocken, 2015) [22]. In addition, this method is a highly accurate and robust numerical simulation model to benefit the design as an effective ventilation strategy to prevent or mitigate infection risks attributed to an indoor environment (Chen & Zhai, 2004) [23]. Numerical solutions are obtained for a steady-state condition by resolving the conservation of mass and momentum equations, with the turbulence model used being the standard k-ε model. The simulation will be experimented with four strategies with different combinations that are presented in Table 1.

Simulations are carried out using the software Ansys Fluent Student version. 2024 (Ansys Academic Research Ansys Fluent, 2024) [24]. The model was created following the existing situation, where the inpatient room consists of 5 patient beds with ventilation elements in the form of AC, exhaust fan, and windows, Fig. 1. The purpose of the simulation is to see the effect of various types of existing ventilation scenarios on the air flow and thermal conditions in the inpatient room.

a. Provide fairly even air flow in the room,
b. Provide comfort for patients, and
c. Allows the exchange of dirty and clean air to prevent the risk of airborne disease transmission.

There were 4 ventilation scenarios tested in an inpatient room, consisting of various types of windows, air conditioning, and exhaust fans. Table 1.

Table 1: Various types of existing ventilation scenarios

Scenario	**Window** Pressure 0 Pa / Inlet 1 m/s	**AC** inlet 1 m/s, direction of fan blade 45°	**Exhaust fan** Pressure jumps 0 Pa
1	Open (inlet/outlet)	On (inlet)	On (outlet)
2	Close	On (inlet)	On (outlet)
3	Open(inlet)	Off	On (outlet)
4	Open (outlet)	On (inlet)	Off

2.2 The position of air flow and temperature data in the Budi Kemuliaan Inpatient room plan

This research was conducted in a class 2 inpatient room consisting of 5 beds in the Budi Kemuliaan Hospital building on Batam Island. The floor plan can be seen in Figure 1 below.

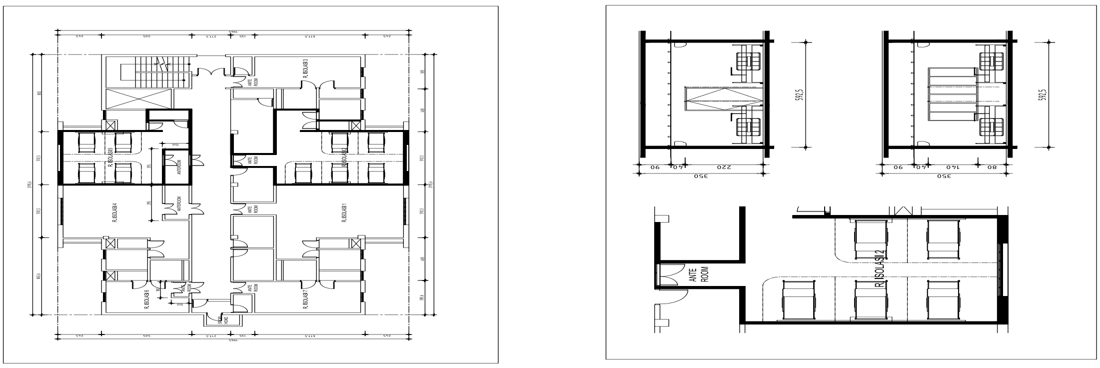


Figure 1: Budi Kemuliaan Batam Hospital Inpatient Room Plan

The position of the air flow and temperature data sample fields is located in the inpatient room, Fig. 2.

a. Middle AC-bed area
b. Front AC-bed area
c. Window-mattress plane
d. Window-door-exhaust area

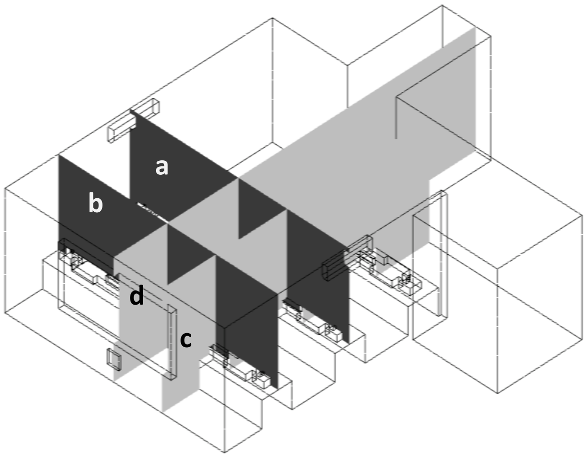
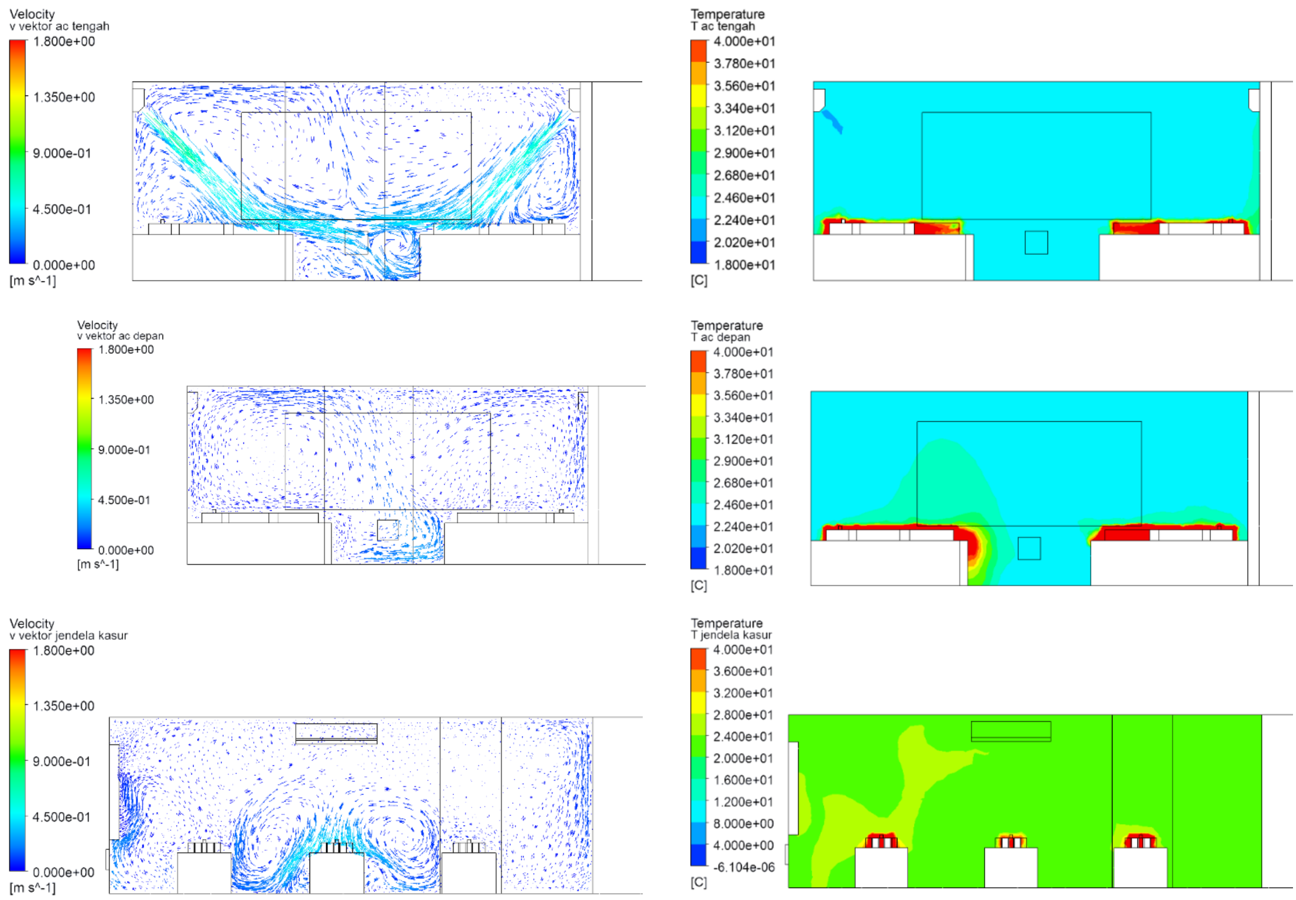


Figure 2: The position of the air flow and temperature data sample fields

2. FINDINGS AND DISCUSSIONS

The four scenarios exemplify potential and practical strategies to examine both combination mechanical and natural ventilation, then lead to comparing more impactful combinations to reduce infectious transmission in an inpatient hospital ward through the air ventilation system. The combination of parameters, both mechanical and natural ventilation, is influenced by a number of positions, locations, surface dimensions, and air flow direction in each bed of the inpatient ward. Those variables result sort of different configurational range in the distribution of air flow, patient's comfort, and circulation aspects, including air exchange, windows, and exhaust grilles.

Scenario 1: Combination of Window Open, AC On, Exhaust On



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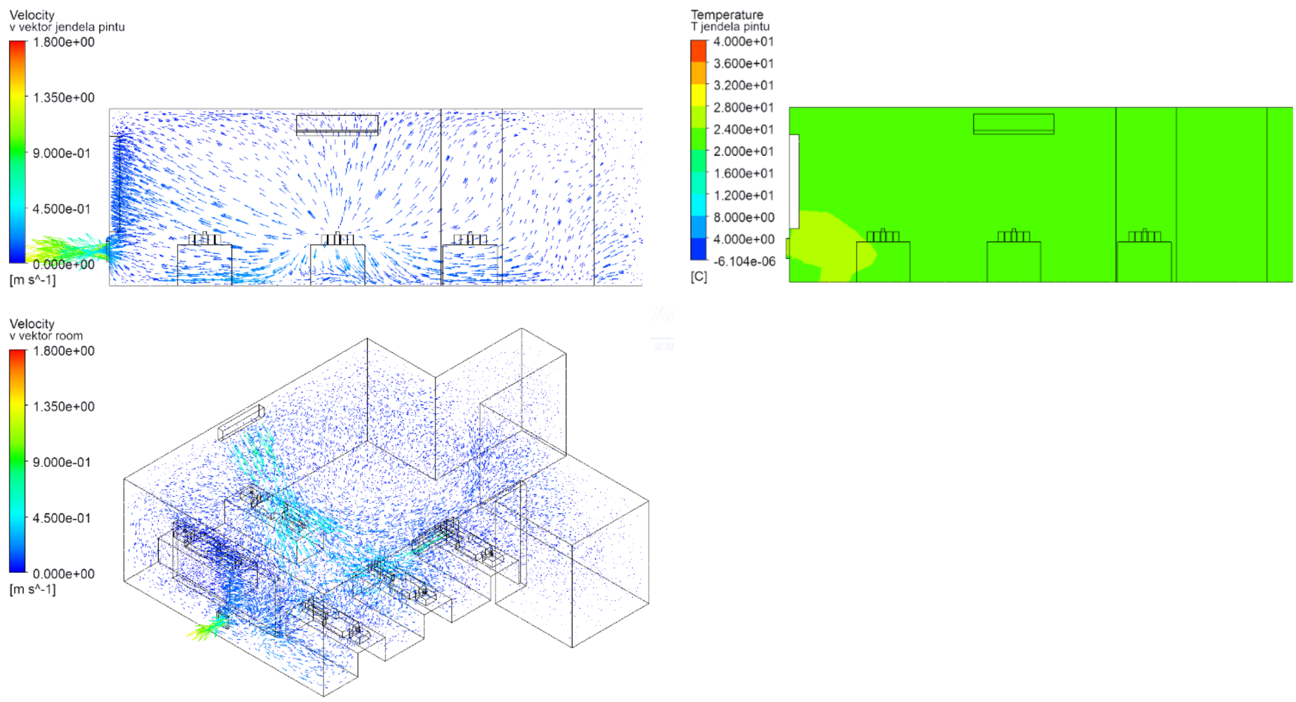


Air velocity = 0.0705 m/s T= 23.66 °C

Figure 3 Scenario 1 Combination of Window Open, AC On, Exhaust On

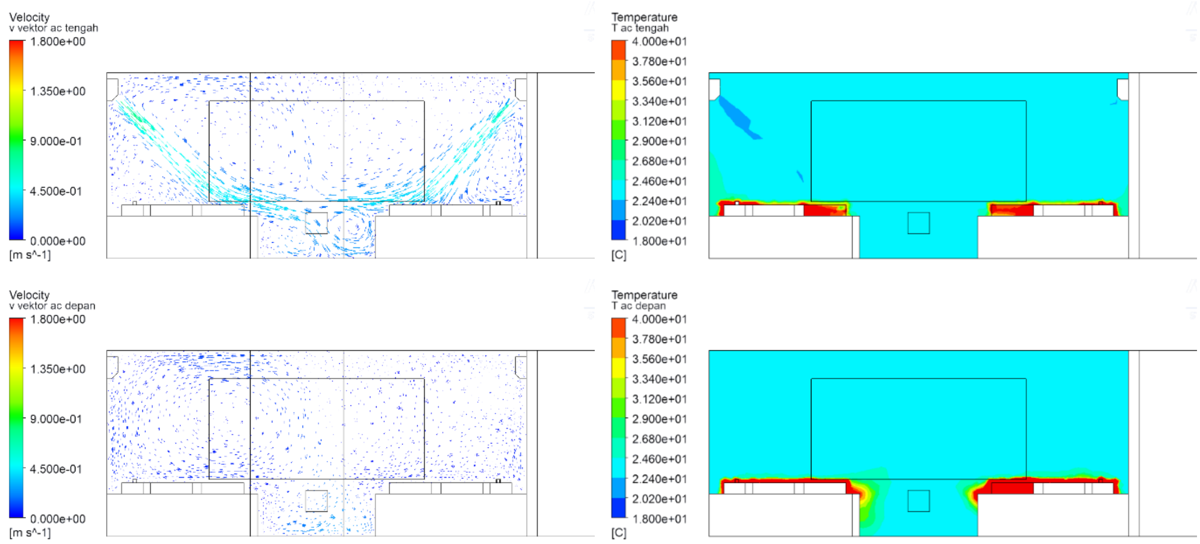
The result from Simulation Scenario 1 combination of Window Open, AC On, and Exhaust On, is described below:

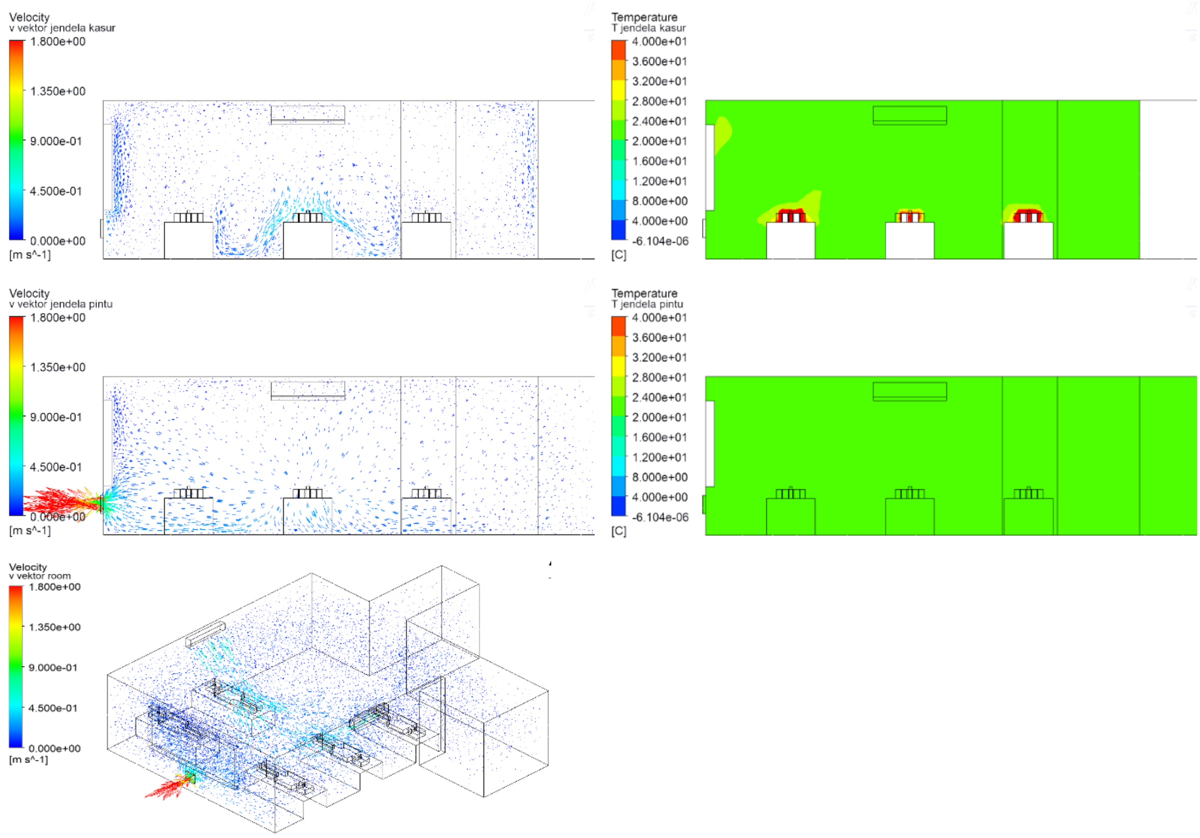
a. Distribution aspect, movement of air flow concentrated in the center of the room. The back side of the room (near the exit) has the weakest airflow. The main window in this scenario functions as an outlet.

b. Patient Comfort, patients in the middle bed of the inpatient room are uncomfortable because they are at the center of air flow turbulence. The room temperature conditions meet a comfortable standard, but the effectiveness of the AC is reduced because the windows are open.

c. Air exchange, windows, and exhaust play a role in removing dirty air from the room. However, because the inlet is in the middle of the room, the air on the back side can experience re-circulation, or the air takes a long time to leave the room.

Scenario 2: Combination of Window Close, AC On, Exhaust On





Air velocity = 0.07278 m/s T = 23.16 °C

Figure 4 Scenario 2 Combination of Window Closed, AC On, Exhaust On

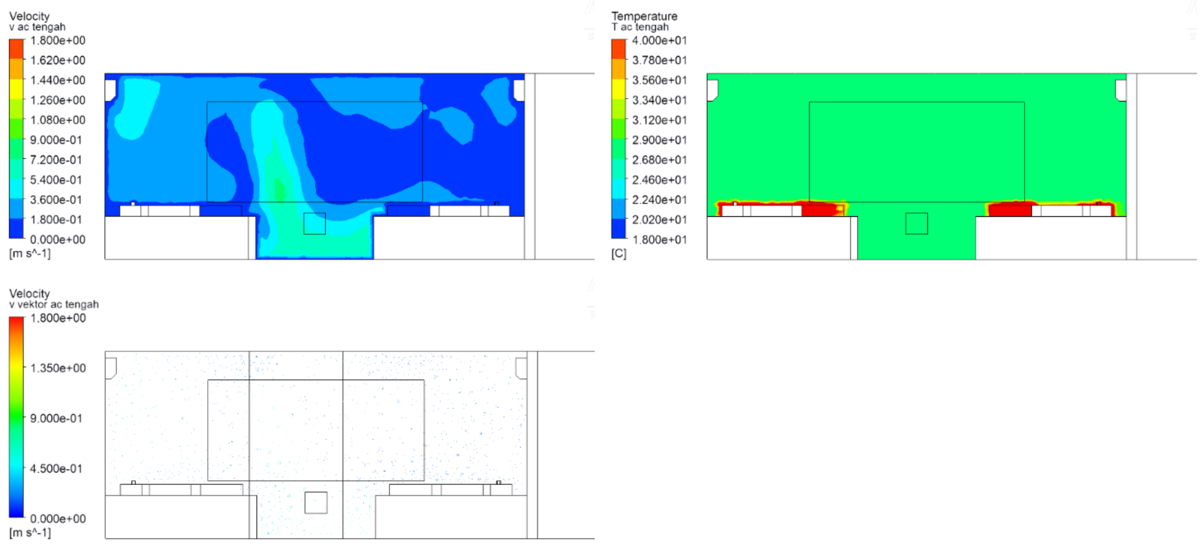
The result from Simulation Scenario 2 combination of Window Closed, AC On, and Exhaust On, is described below:

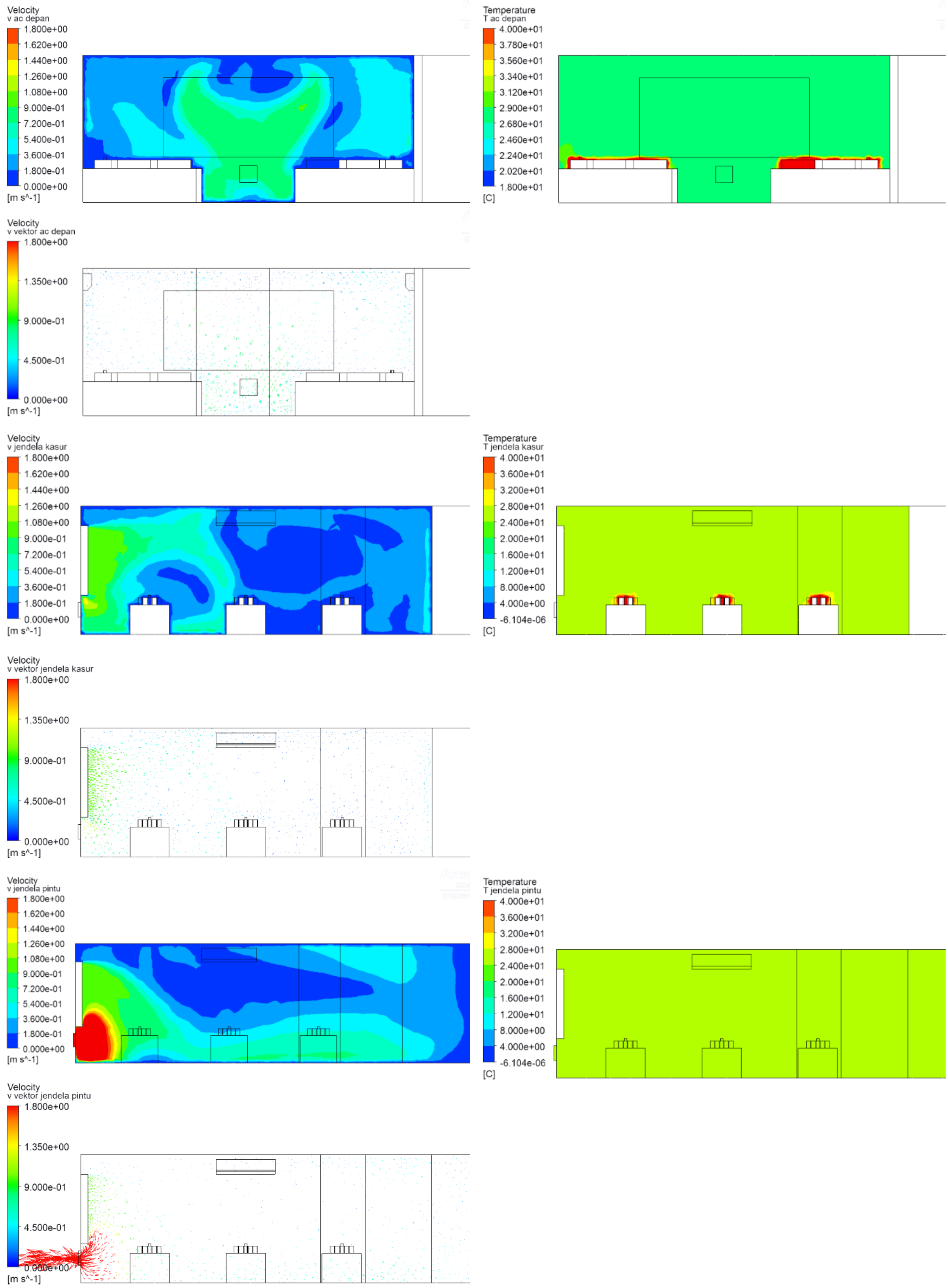
a. Air flow distribution aspect, the movement of air flow is concentrated in the center of the room. The side of the room near the exit has the weakest air flow. The air pulled in the exhaust is stronger because it is the only outlet point.

b. Patient comfort, the patient in the middle is uncomfortable because he is at the center of air flow turbulence. The lowest temperature is because the AC can work effectively.

c. Air exchange, exhaust plays a role in removing dirty air from the room. However, because the inlet is in the middle of the room, the air on the side of the room near the door may experience re-circulation or take a long time to be drawn out of the room. The nature of AC is to return and cool the air in the room, so windows still need to be opened on a scheduled basis to supply new, clean air into the room.

Scenario 3: Combination of Window Open, AC Off, Exhaust On (1m/s)

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1.620e+00
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1.080e+00
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1.800e-01
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Temperature
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3.780e+01
3.560e+01
3.340e+01
3.120e+01
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2.680e+01
2.460e+01
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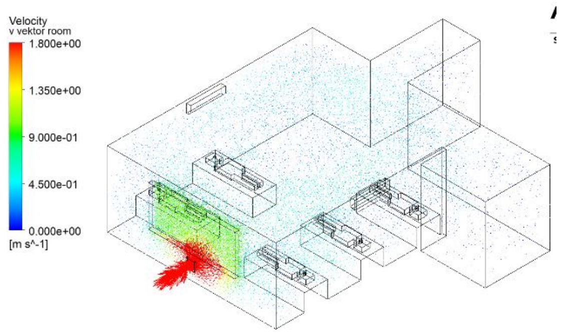


Air v = 0.4917 m/s T = 27 °C

Figure 5 Result Scenario 3 Combination of Window Open, AC Off, Exhaust On

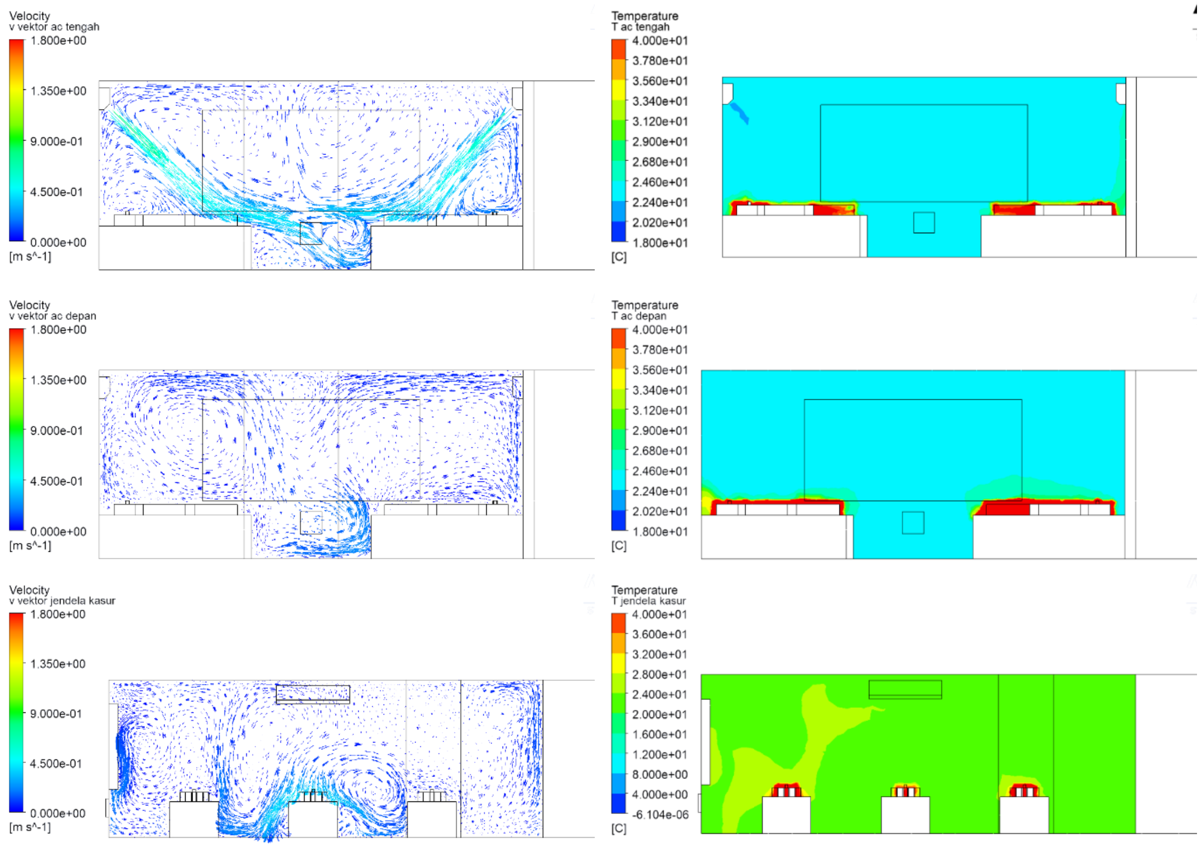
The result from Simulation Scenario 3 combination of Window Open, AC Off, and Exhaust On, is described below:

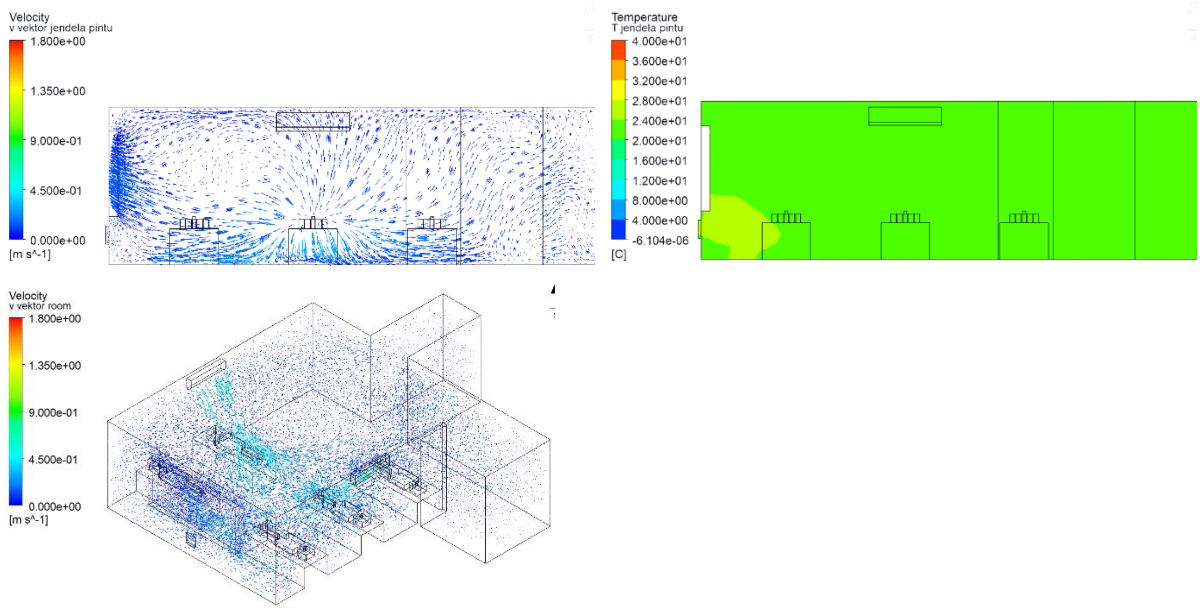
a. Air flow distribution aspect, air flow movement only occurs at the front (side of the facade) of the room, while the air inside the room tends to remain still. The air pulled in the exhaust becomes very strong because extreme positive and negative pressure is formed on the facade.

b. Patient comfort aspect, the patient near the window does feel air movement, but because of the high-pressure difference (the air flow is quite fast, depending on the wind speed at the window), it can cause discomfort. Meanwhile, in other parts of the room, the air is still, making it uncomfortable. The highest temperature follows the outside air temperature.

c. Air exchange aspect, air exchange only occurs on the facade side, while the air inside the room is still and is not exchanged with new air.

Result Scenario 4 Combination of Window Open, AC On, Exhaust Off (1m/s)



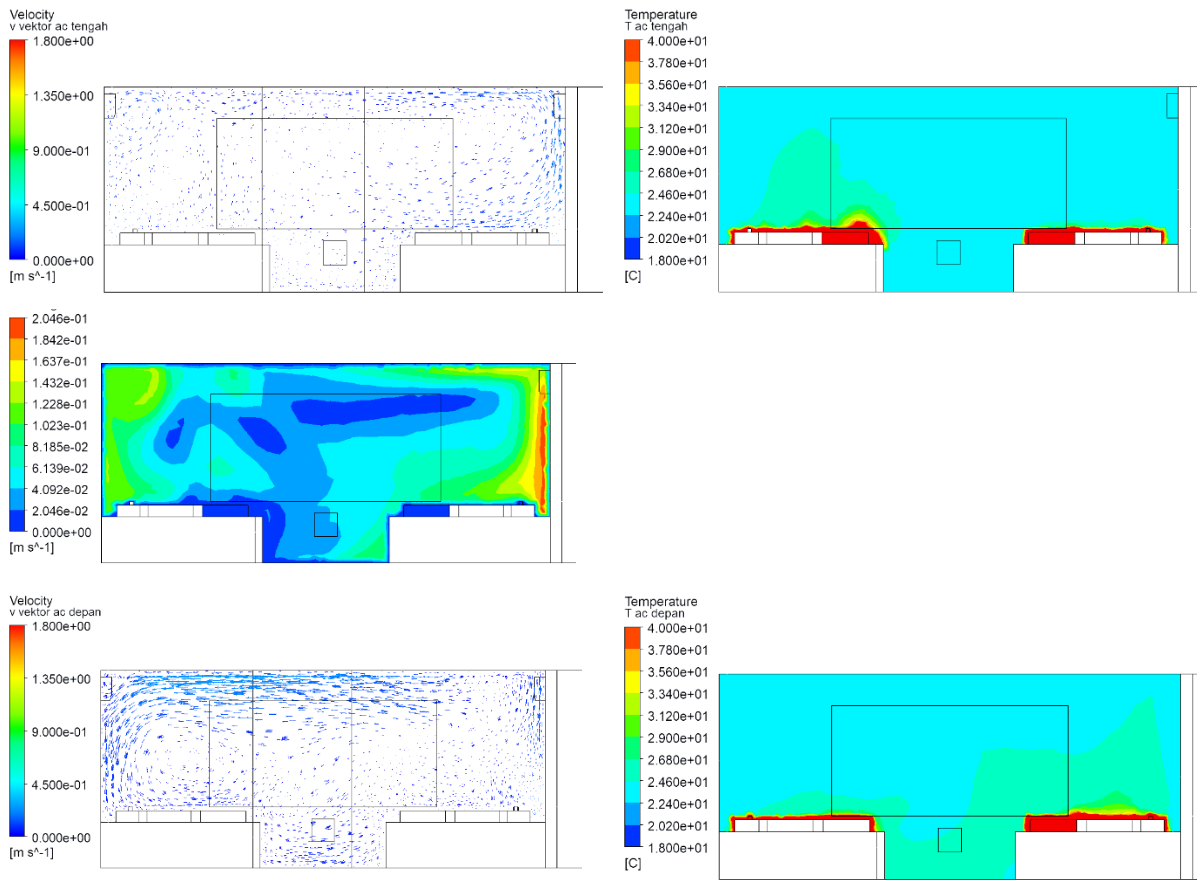


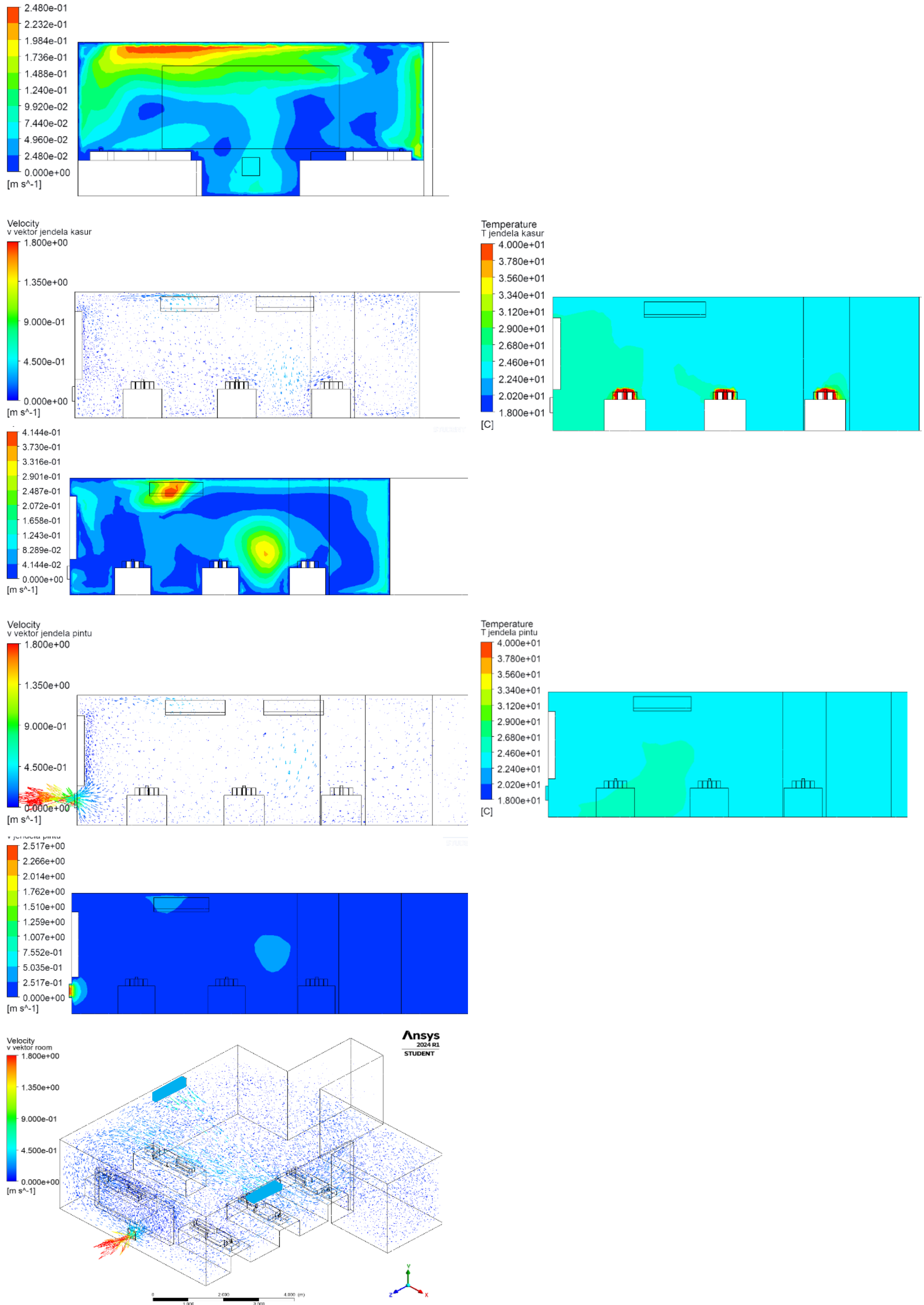
Air v = 0.0697 m/s T= 23.55 °C

Figure 6 Scenario 4 Combination of Window Open, AC On, Exhaust Off

Design Improvement: Combination of Window Close, AC On, Exhaust On

From all the simulated scenarios, it was found that scenario 2 is the relatively best condition, but still has weaknesses. The weakness of Scenario 2 is that the AC position facing away will cause air turbulence, making the patient uncomfortable. To improve the design, layout changes were made by placing the AC not face each other and placing the exhaust fan blade at a flat angle. Design improvements were then simulated with results as shown in the image below.





Air v = 0,07111 m/s T = 24,1383 °C

Figure 7. The Simulation result of Scenario 4: Combination of Window Open, AC On, Exhaust Off

The Simulation result of Scenario 4 Combination of Window Open, AC On, and Exhaust Off, is described below:

a. Air flow distribution aspect, movement of air flow concentrated in the center of the room. The back side of the room (near the exit) has the weakest airflow. The window works as an outlet.

b. Patient comfort aspect, the patient in the middle is uncomfortable because he is at the center of air flow turbulence. For temperature, it meets comfortable standards, but the effectiveness of the AC is reduced because the window is open.
c. Air exchange aspect, air exchange is unstable because it really depends on the pressure & wind speed at the window. In addition, because the inlet is in the middle of the chamber, the air on the back side may experience re-circulation or take a long time to be drawn out of the chamber.

3. CONCLUSION

From the four simulated scenarios, scenario 2, with AC as the air inlet and exhaust fan as the air outlet, with full mechanical ventilation conditions, is the best. The AC supplies a stable and adjustable air flow, as does the exhaust fan, which can draw dirty air in a stable manner. By closing the windows, the AC can also work effectively to cool the air in the inpatient room.

From the simulations carried out, weaknesses were found in the existing design of the inpatient room in terms of air circulation. First, the position of 2 air conditioners in the middle of the room, facing each other, causes the distribution of air flow to be less evenly distributed to other areas in the inpatient room. Second, the positioning of the AC and the blade direction of the exhaust fan are too downward, which will cause discomfort to patients who are at the AC point because the air flow speed is too fast. In the design of inpatient care for airborne diseases such as COVID-19, to ensure that new, clean air enters the room, windows still need to be opened on a scheduled basis for a short duration. From the simulations carried out in this research, in inpatient design it is necessary to maintain patient comfort, specifically by considering the position of the AC so that the speed and direction of the air flow is not above the patient, and if more than 1 AC unit is used, the placement of the AC units is spaced so that the air flows more evenly. From the simulation of the 4 scenarios, it was found that the tilt of the fan blade of the exhaust fan has a significant impact on the circulation (turbulence) of air in the room, which can affect the comfort of the patient. As a result, it needs to be adjusted to suit their needs.

The results of this research can be used to design a better air circulation system for inpatient care in wards or hospitals specializing in airborne infectious diseases. The ideal condition is to place patients in isolation rooms with one patient in one inpatient room; however, for hospitals with limited funds, inpatient rooms can be designed with more than one patient, but with a special design that pays attention to air circulation aspects.

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Disclosure statement

No potential conflict of interest was reported by the author(s)

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