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Ventilation Performance of Air Duct in Double Loaded Corridor Building: A Case Study

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Abstract

Buildings with double-loaded corridor types are often found in Indonesia and generally function as offices or lecture rooms. This type of building is popular because of its efficient circulation path to accommodate the movement of occupants. However, a wall separating the room from the corridor makes it impossible to put windows to implement a cross-ventilation system due to acoustic problems. Hence, to achieve indoor thermal comfort, this type of building relies on using an air conditioning (AC) system. However, with the WHO's call to reduce the use of AC during the COVID-19 pandemic, it is necessary to evaluate cross-ventilation in double-loaded corridor buildings to meet comfort standards while still preventing acoustic problems due to noise from corridors and other spaces. The study proposes a new natural ventilation system using air ducts placed above the corridor ceiling to create cross-ventilation in lecture buildings. The E-ITERA building was chosen as a case study in this research. The building has a glass facade with several small windows that can be opened outside. The corridor of this building is designed with openings at both ends, allowing for direct connection to the outside air. The walls facing the passage have a single door and four small ventilations on the aisle's upper side. Simulations were carried out in two classrooms on the 3rd floor using CFD (Computational Fluid Dynamics) software. Experiments were carried out to change the size of the air duct and the size of the ventilation on the wall that leads to the corridor. The results showed that the air duct was able to create cross-ventilation. Ventilation performance is improved when the WWR air duct is the same as the WWR window. The highest air velocity in the centre of the room is 0.6 m/s.

Keywords: Air Duct; Cross Ventilation, Covid-19; Double Loaded Corridor, Ventilation Performance.

1. Introduction

In Indonesia, the double-loaded corridor-type buildings are mostly used as private offices, government, residential, and educational buildings. This type of building is generally designed to rely on air conditioners (AC) as the main or only ventilation system to maintain thermal comfort. The use of air conditioners is inseparable from Indonesia's hot climate conditions and the limitations of the double-loaded corridor design in maximising natural ventilation; however, with the COVID-19 pandemic, which is mainly transmitted airborne [1], WHO does not recommend using an AC system due to low air turnover. The recommendation is prioritised in spaces occupied by many people for a long time. Because COVID-19 can remain in the air for up to three hours, air conditioners (AC) may still be used if they minimise recirculated air [2]. This condition will lead to an increase in energy consumption, making the building more environmentally unfriendly.

Air conditioning systems can be integrated with natural ventilation systems. When climatic conditions allow for thermal comfort, natural ventilation systems are used. Meanwhile, an air conditioning system maintains thermal comfort

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when conditions are unfavourable. Combining the two can reduce energy consumption by 30%–79% [3–5]. The level of energy consumption efficiency is highly dependent on local climatic conditions and building design. Applying a natural ventilation system to a double-loaded corridor building has its challenges. Solid walls, generally used to separate rooms and corridors, will likely hinder air movement.

Changing the wall material to perforated or creating excessive apertures can create new issues, such as privacy and noise disturbances for users. Therefore, to reduce reliance on the air conditioning system, it is necessary to conduct a design study that maximises natural ventilation to maintain the air temperature within the comfort zone and meet the indoor air quality [6, 7] while preserving privacy and minimising noise transmission. The ventilation system in this type of building is generally of the single-sided ventilation (SSV) type. Extensive research has been conducted on SSV, including the combination of SSV with automatic control [8] and the influence of facade design [9]. Unfortunately, single-sided ventilation's efficacy is inferior to cross-ventilation [10]. Besides, very little previous research has been conducted on cross-ventilation in double-loaded corridor buildings. Existing research is related to educational facilities, with aspects reviewed in corridors and air ducts [11, 12]. Other studies, however, in apartment buildings have also been carried out regarding the aspect of openings in corridors and voids [13, 14].

Cross-ventilation systems are easier to adopt in existing buildings than stack ventilation, as they do not require major renovations. Apart from that, the wind speed in Bandar Lampung is quite strong, between 2-4m/s as in Figure 1. This system takes advantage of the pressure difference between the inlet and outlet, so determining the location of the two is very important. Besides that, other aspects also affect the performance of cross ventilation, such as the orientation of the building to the wind, layout, dimensions, and placement of inlet outlets [15, 16]. This study revealed the influence of air duct dimensions and the effect of window size on cross-ventilation performance in double-loaded corridor buildings.

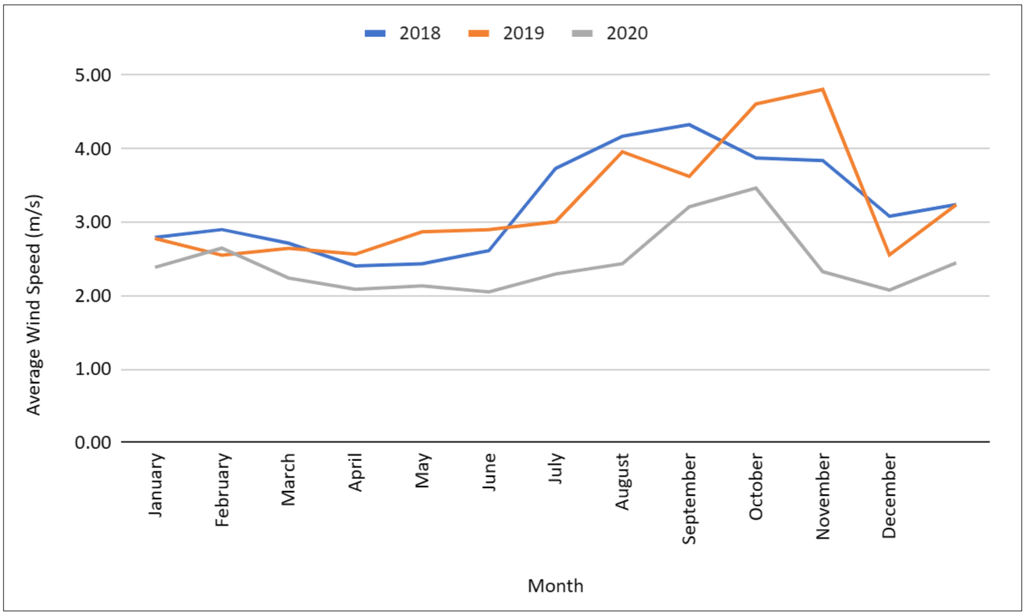


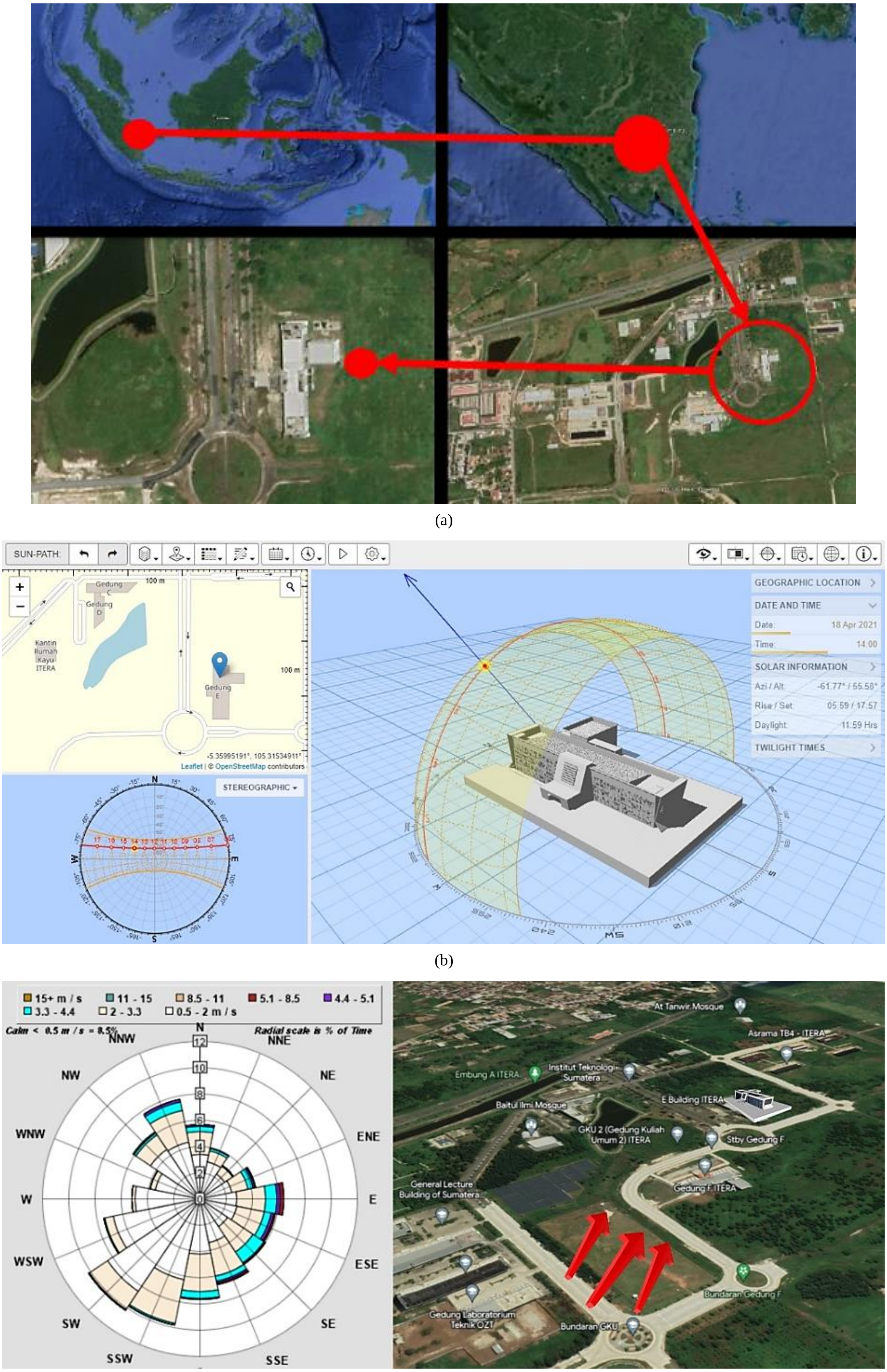
Figure 1. Graph of average wind speed of Bandar Lampung

2. Research Methodology

This digital experimental research was conducted on a case study of an educational building in Lampung, Indonesia. The first stage of this research is the initial observation of the building to get first-hand experience of the actual case study conditions. Comments were made by direct visits to facilities, obtaining construction drawings and field measurements to determine the indoor air temperature in lecture halls. After that, 3D modelling was created, and digital simulations were carried out to observe wind movement, distribution, and speed using Computational Fluid Dynamics (CFD) to obtain ventilation performance for air ducts in double-loaded corridor buildings.

2.1. Building Description

This research was conducted in a case study of the lecture building in building E of the Sumatra Institute of Technology (ITERA), which is located in South Lampung, Indonesia (5°21'36.3"S and 105°18'55.5"E), as shown in Figure 2-a. The environment around the building is overgrown with grass; no buildings or vegetation can be used as sun protection around this building. As it is free from buildings and vegetation in the downwind direction, the building corridor still receives wind flow from the southwest. Figures 2-b and 2-c show the trajectory of the sun on the test day and the wind rose and wind direction in the building case study, respectively. The longitudinal planes of the glass structure are mostly exposed to direct sunlight.



(a)

(b)

(c)

Figure 2. a) Location of the case study, b) The solar path on the testing day, c) The wind rose and wind direction to the case study building

This building has a double-loaded corridor with three floors above the ground and one additional floor at a lower elevation than the lobby. The building faces east and west (long side) and north-south (shorter side). A 100% WWR glass wall dominates the façade of the building—several awning windows of 80 × 100 cm^2, six pieces per 12 m (Figure 3). The building has a 2.5 m wide corridor, dominated by solid walls with two openings at the ends. Along the wall of the aisle, the side is provided with hanging windows of the size of 50 × 100 cm^2. The windows are located in four pieces per 12 m.

Figure 3. Perspective, Section and Corridor of E Building

Measurements of air temperature and relative humidity (RH) were carried out from June 6–12, 2021, in several rooms of building E (Table 1). Measurements were made with the air conditioner off, doors and windows closed, and no activity in the room. The measurement results show that the hottest temperature reaches 34.1 °C with an average of 25.8–28.5 °C, and the RH is 42.9–79.7%. The hottest average temperature was obtained at 3:00 p.m. The high air temperature (outside the comfort zone [6]) occurs due to the orientation of the building facing east-west and the exterior wall material being dominated by glass. Simulations were carried out in rooms E303 and E304. These spaces are opposite each other, as shown in Figure 3.

Table 1. Field measurement at 8:00-17:00

Room	Orientation	Temp Max (^{0} C)	Temp Min (^{0} C)	Av. Temp (^{0} C)	RH Max	RH Min
E103	West	34.1 (15:00)	25.8	29.66	74.1	42.9
E104	East	33.9 (12:00)	28.5	30.5	76.1	51.5
E203	West	33 (15:00)	28.4	29.7	79.7	59.9
E204	East	30.9 (12:00)	26.7	28.3	67.7	48
E303	West	32.3 (15:00)	28.1	30.36	78.2	56
E304	East	31.8 (15:00)	27.9	30.1	69.5	49.7

Observation of the movement, distribution, and wind speed is done digitally using computational fluid dynamics (CFD). This method has been widely used to observe air movement. Several experiments were carried out to obtain better natural ventilation performance [17–20]. Existing conditions are used as a basis for comparison, and variation is introduced by enlarging the corridor side window and introducing air ducts of varying diameters to connect the rooms. Experiment details can be seen in Table 2. Horizontal wind profile observations were carried out at a height of 1.2 m from the floor surface. 1.2 m is the height of a person's head when sitting, according to ASHRAE Standard 55. Vertical wind profile observations were made at the room's 1.2 and 2.4 m centerlines.

Table 2. Details of Model Variation

	Air Duct Variation			Window Variation		
	AD-1	**AD-2**	**AD-3**	**J-1**	**J-2**	**J-3**
Air duct Height	30 cm	40 cm	50 cm		30 cm	
Air duct width	12 m					
DWR	9%	12.1%	15.2%		9%	
Window Height (exterior wall)	50 cm					
Window width (exterior wall)	80 cm/ window			100 cm/ window	120 cm/ window	140 cm/ window
WWR	6%			7.6%	9%	10.6%

2.2. 3D Modelling and Boundary Condition

CFD simulation requires precision in determining the correct domain size; a too-small domain can result in inaccurate simulation results. Some references provide minor variations in the domain size that must be specified. In this simulation, the domain setting follows the best practice conducted by Ramponi & Blocken [18]. The spacing of the windward 5H, Leeward 15H, and Height 6H domains is shown in Figure 3. The building block area is 4%, lower than the recommended maximum of 5%. The angle of incidence of the wind is perpendicular to the building. The wind speed profile in the inlet domain uses the power-law formula [21]:

$$Vz = Vg\ (Z/Zg)\alpha \tag{1}$$

The gradient height and mean speed exponent were determined using the values established by Aynsley et al. [21]. Terrain roughness uses the suburban category because the location of the building is on the outskirts of Bandar Lampung and is only surrounded by trees and open fields. Wind speed data from Bandar Lampung in 2018–2020 was calculated using wind speed data from MKG ITERA (Figure 4). Setting the outlet using the outflow [22]. A summary of the simulation settings can be seen in Table 3.

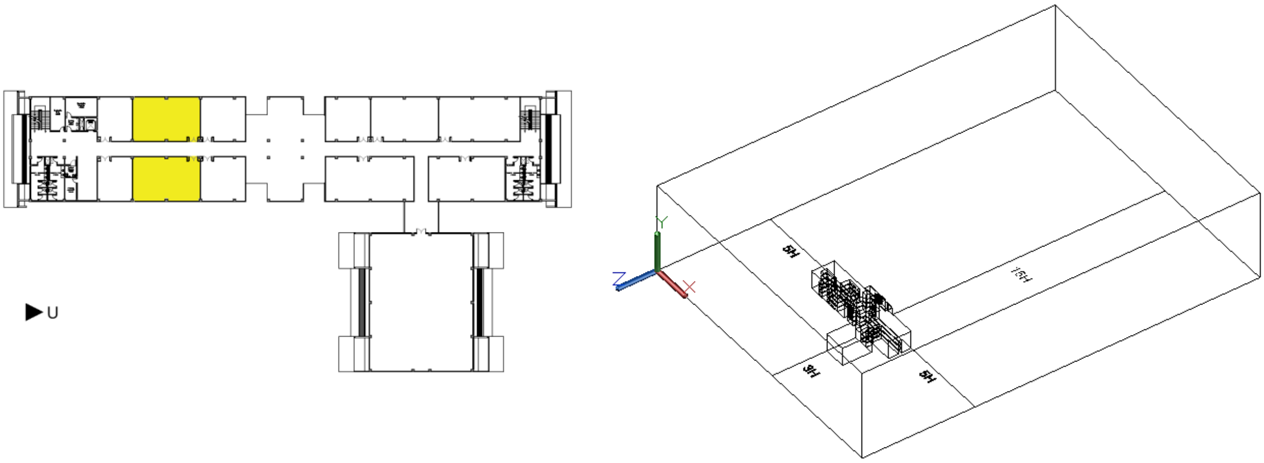


Figure 4. Observation room at E Building (left), Domain size (right)

Table 3. Simulation Settings on CFD

Outlet	Outflow [22]
Wind velocity	Gradient height [23]
Wind Orientation	0
Domain wall	Specified shear (shear stress = 0)

2.3. Mesh Quality

The mesh quality greatly determines the level of truth of the simulation results. Therefore, in generating the mesh, it is necessary to use the right method. This simulation develops the mesh using the sizing, proximity, and curvature methods. The relevance centre is set to fine. Assembly meshing uses the tetrahedrons method, with the largest size limited to 4-5 m. The quality of the resulting mesh is determined based on the aspect ratio and skewness. A good aspect ratio is below 20, and the closer the skewness is to 0, the better. The average values of the two aspects, respectively, are 1.852 and 0.233, which means it has good quality. The mesh quality is shown in Figure 5.

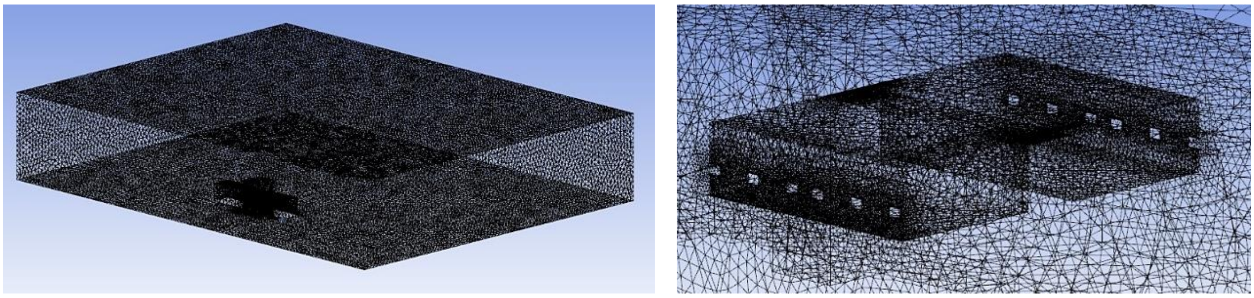


Figure 5. Domain mesh quality (left), Room mesh quality (right)

2.4. Solver Setting

The simulation uses the RNG k-e equation with a standard wall function. This equation is used because it is fairly accurate for simulating air movement in buildings and is cheap compared to LES. However, LES has better accuracy [24]. This equation has been widely used for airflow simulations with low error rates. This equation is combined with the SIMPLE algorithm using pressure velocity coupling and first-order upwind discretisation for turbulent kinetic energy and turbulent dissipation rate [22]. The iteration is carried out until the monitored results show a stable value. The work steps of the simulation process have been presented in Figure 6.

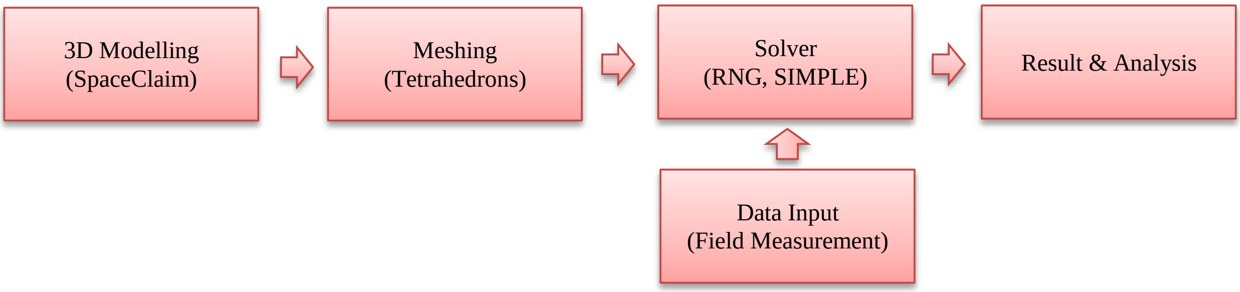


Figure 6. Work steps of simulation process

3. Results and Discussion

3.1. Impact of Air Duct Size Variation

The simulation results show that the airflow velocity at an altitude of 1.2 m in the windward side room is much higher than in the leeward side room. It occurs in all Air Duct variation dimensions. At the same time, the airflow velocity at an altitude of 2.4 m in the windward and leeward side rooms is not much different except in the AD-3 model, where the wind speed in the leeward room is much lower than in the windward room.

The airflow in the windward room starts to move up towards the Air Duct at the ½-¾ depth of the room. Changes in airflow occur when the air jet loses its velocity and mixes with the air in the room. Eddy forms in front of the corridor side walls and behind the upper exterior walls because there are no openings in these areas. In both regions, the movement and change of air occur very slowly.

Observations at 1.2 m height carried out in the windward room models AD-1, AD-2, and AD-3 showed that the airflow in the windward room moved slower with the larger size of the Air Duct. It can be seen in Figure 7, where the airflow velocity in the middle of the space of the three models is 0.7 m/s, 0.4 m/s, and 0.3 m/s, respectively. This phenomenon occurs because the area of the window opening is smaller than the area of the ducting outlet in AD-2 and AD-3, which causes a reduction in the air pressure difference in the chamber and around the air duct (Table 4).

Table 4. Ventilation Rate of Air Duct Size Variation

Variation	Ventilation Rate	Percentage
AD-1	4.60 m^3/s	100%
AD-2	4.56 m^3/s	99.1%
AD-3	4.08 m^3/s	88.6%

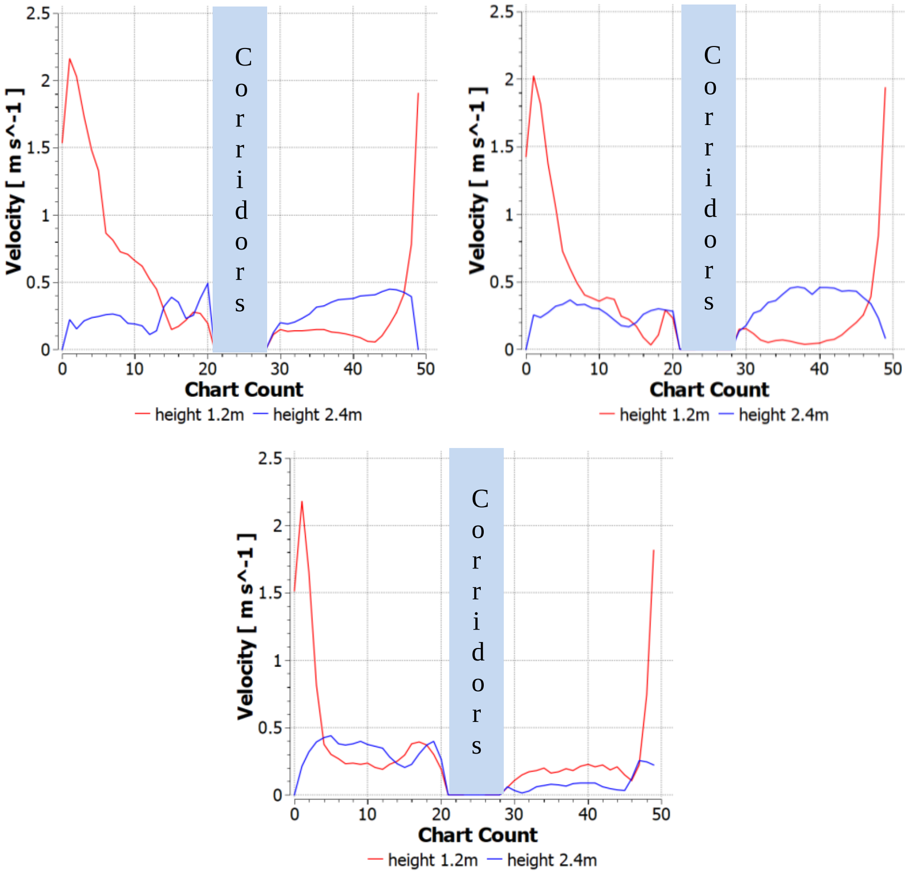
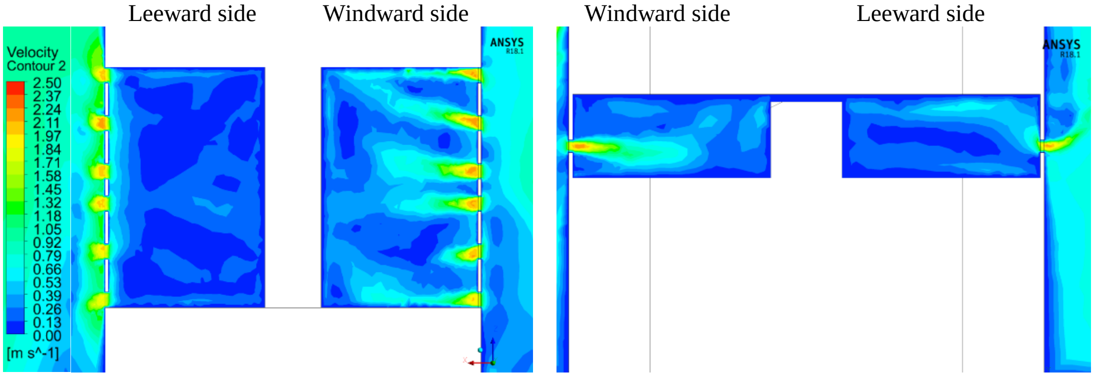


Figure 7. Air Velocity in The Rooms of AD-1, AD-2, and AD-3

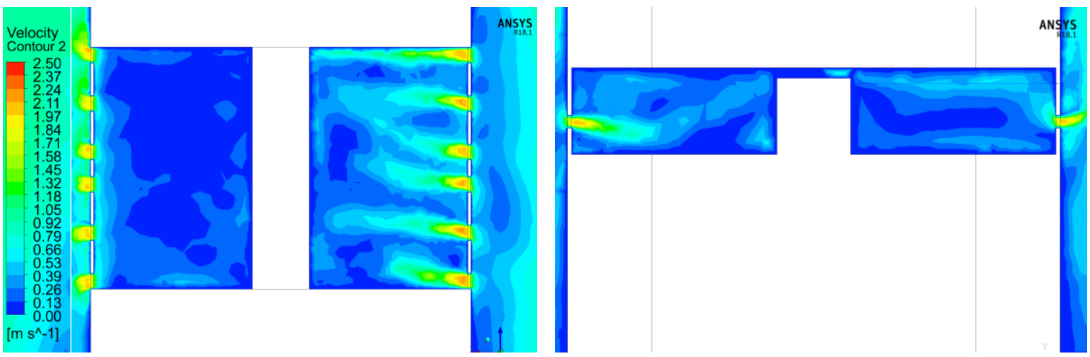
Air movement in the leeward room of the three models at a height of 1.2 m did not show any difference. However, at an altitude of 2.4 m, there was a slowdown in air movement. At the observation point, the airflow velocity in the three models is 0.4 m/s, 0.45 m/s, and 0.1 m/s (Figure 7). The slow airflow direction in the AD-3 model makes the ventilation rate the lowest among the other two models (Figure 8).

Plan View Section View

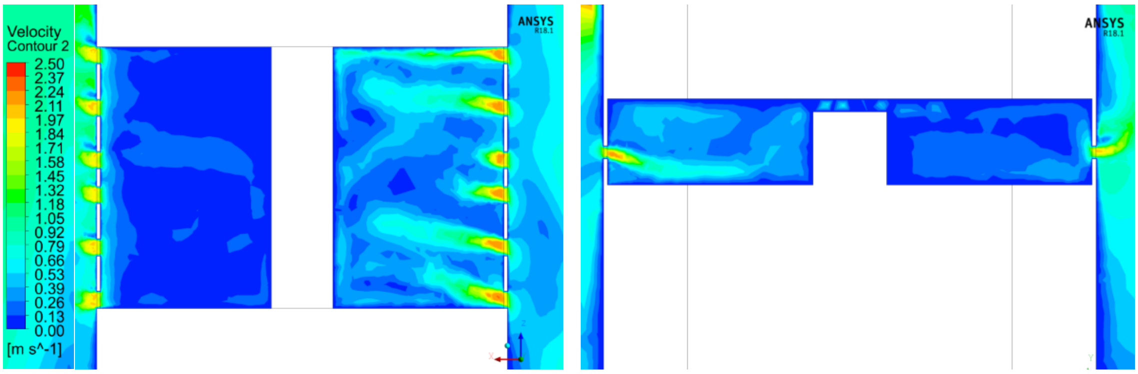
Leeward side Windward side Windward side Leeward side



Variation AD-1



Variation AD-2



Variation AD-3

Figure 8. Airflow contour, window dimension variation

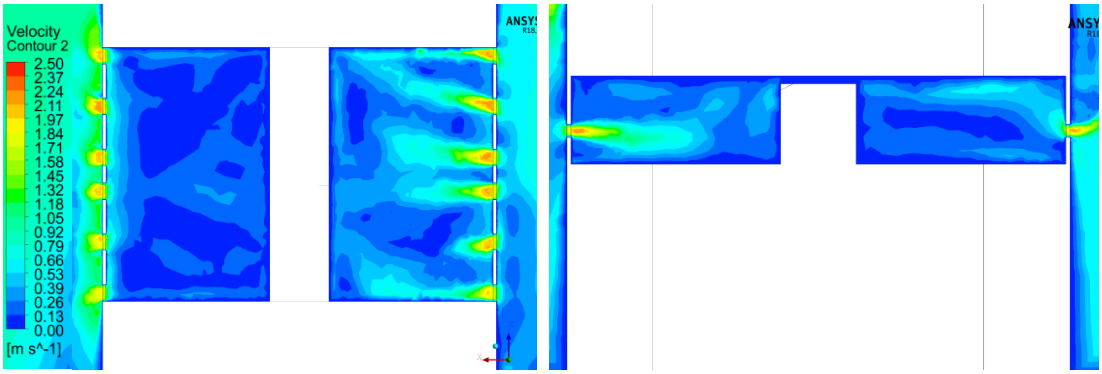
The conclusion that can be drawn is to increase the dimensions of the Air Duct without increasing the size of the inlet and outlet. In this case, the WWR inlet and outlet are smaller than the DWR Air Duct, causing a decrease in airflow speed in the windward and leeward rooms.

3.2. Impact of Window Size Variation

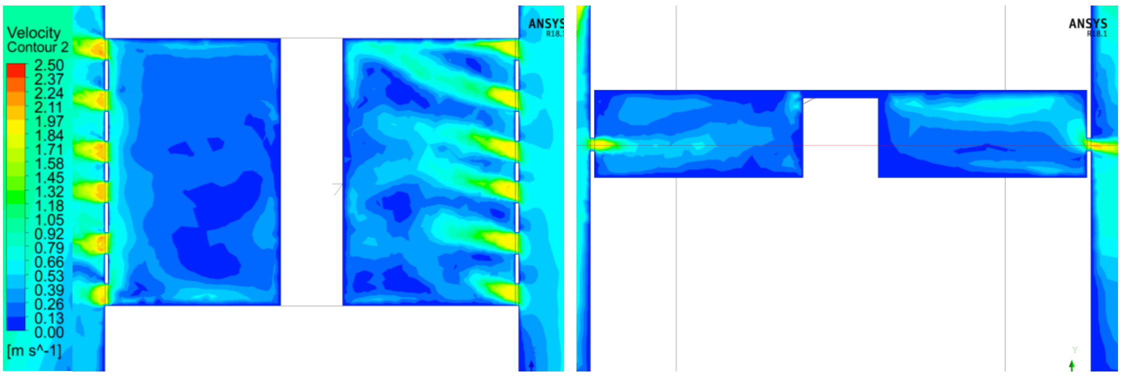
The simulation results show that the airflow velocity in windward rooms is higher than in leeward rooms, as in the model with variations in air duct size. However, the ventilation performance produced by the interpretation of the window size is better than the variation in the air duct size. The direction of airflow movement when entering the room shifts obliquely as the size of the window increases. Although the airflow outside is moving in the same direction, a smaller window can better change the direction of the incoming airflow so that it moves perpendicular to the window (Figure 9).

Plan View Section View

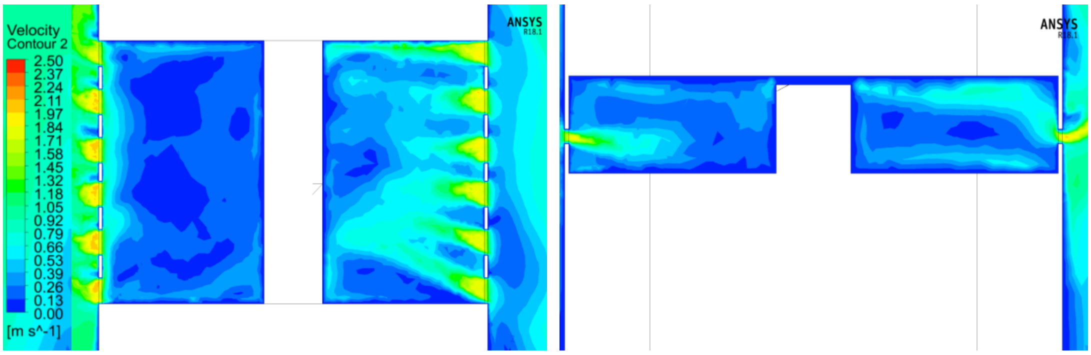
Leeward side Windward side Windward side Leeward side



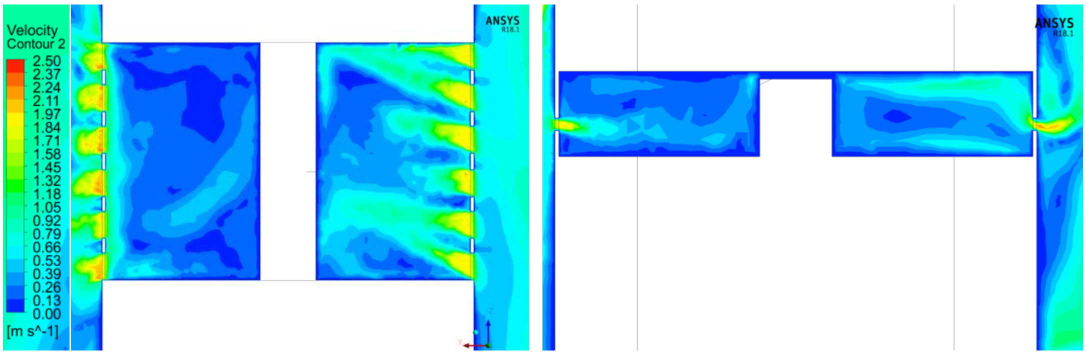
Variation AD-1



Variation J-1



Variation J-2



Variation J-3

Figure 9. Airflow contour comparison of AD-1, J-1, J-2, J-3 Models

Observations at the height of 1.2m show that the larger the WWR window causes a more even airflow distribution, and the average wind speed increases in windward rooms. However, leeward rooms had no significant change (Figure 10). Different things are shown at a height of 2.4m. The airflow velocity in windward rooms does not change; in leeward rooms, the air moves faster as the size of the window increases. However, when the WWR window is larger than the WWR air duct, airflow velocity in the leeward room did not show an increase (Table 5). The conclusion that can be drawn is that natural ventilation can work optimally when the WWR air duct is as large as the WWR window.

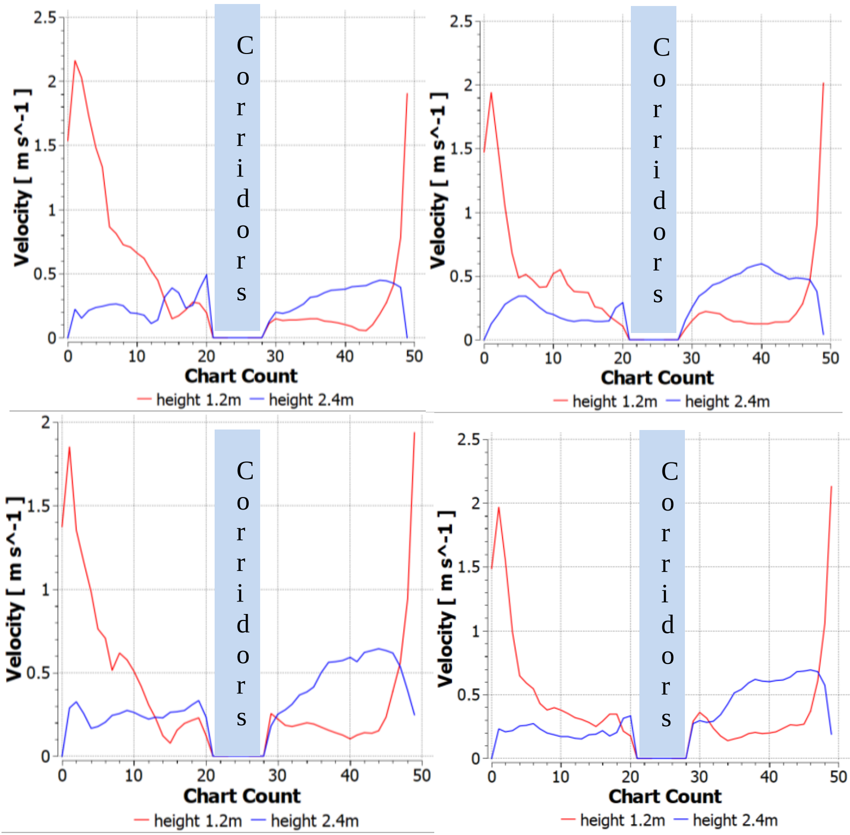


Figure 10. Air Velocity in The Rooms of AD-1, J-1, J-2, J-3

Table 5. WWR Ratio of Window to Air Duct and Air Velocity in The Middle of Leeward Room

Model	DWR Air Duct	WWR Window	Ratio WWR	Air Velocity
AD-1	9%	6 %	0.67	0.4m/s
J-1		7.6 %	0.84	0.6m/s
J-2		9 %	1	0.65m/s
J-3		10.6 %	1.18	0.65m/s

4. Conclusion

Double-loaded corridors are the buildings most often used as offices or classrooms. This type of building usually has windows in only one part of the room, so very few buildings of this type have a cross-ventilation system. This research was conducted to see the performance of the air duct ventilation system applied to a university building with a double-load corridor type. CFD simulations have been carried out on several models with air duct and window dimension variations. The simulation results show a relationship between the treatment given to the performance of natural ventilation in the room. Air Duct dimensions and Window dimensions influence Air Duct natural ventilation performance in buildings with double-loaded corridors. Suppose the WWR of the air duct is greater than the WWR of the window. In that case, it is possible to increase the ventilation performance by increasing the WWR of the window. The greater the difference between the WWR of the air duct's WWR and the window, the worse the natural ventilation performance. Optimum performance is obtained on the J-2 model with the same WWR air duct and WWR window. The wind speed in the windward and leeward rooms is 0.5 m/s and 0.6 m/s, respectively. The WWR comparison in this paper is carried out on the condition of the wall side of the window and the side of the air duct with the same dimensions. If there is a difference in wall area, what should be compared is the area of window openings and air ducts. Further research can be done by adding an airflow guiding element so that the airflow in the leeward room is not focused on the area adjacent to the ceiling.

5. Declarations

5.1. Author Contributions

Conceptualization, M.S.U. and W.A.; methodology, M.S.U.; software, M.S.U.; validation, M.S.U. and W.A.; formal analysis, M.S.U.; investigation, M.K.; resources, W.A.; data curation, M.S.U. and W.A.; writing—original draft preparation, M.S.U.; writing—review and editing, M.S.U. and W.A.; visualization, M.K.; supervision, W.A.; project administration, W.D.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding and Acknowledgements

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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