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## ORIGINAL RESEARCH PAPER

### The Effect of Wing Walls on Air Velocity Performance in Single-Sided Ventilated Spaces Using CFD

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#### ABSTRACT

Natural ventilation in single-sided spaces often suffers from low airflow rates, which can negatively impact indoor air quality and thermal comfort. Wing walls-vertical panels installed adjacent to windows-offer potential for directing and accelerating incoming airflow; however, their optimal design parameters have not been sufficiently investigated. This study aimed to increase the average indoor air velocity in a single-sided ventilated room by incorporating a wing wall. To achieve this, the ventilation performance of several wing wall configurations with varying depths and angles was analyzed to determine the optimal depth, angle, and location. The results show that using two windows with the same total area, instead of a single window, improves both ventilation efficiency and indoor air velocity. Further enhancement was achieved by adding a perpendicular wing wall to one side of each window, which increased airflow and average indoor air velocity. Increasing wing wall depth further improved performance, with the optimal depth equal to the width of the window. Notably, movable wing walls angled at 15°, 22.5°, and 30° outperformed fixed perpendicular wing walls, delivering superior ventilation effectiveness and higher internal air velocity. This study fills a gap in natural ventilation research by simultaneously evaluating wing wall depth and angle, providing practical design guidelines for architects and engineers. Future research should examine the effects of awnings, varied opening types, movable wing walls at different heights in high-rise buildings, smart designs, and their role in cross ventilation.

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## INTRODUCTION

According to the World Economic Forum's 2019 annual report, climate change is the most pressing global threat facing the planet (World Economic Forum, 2019). The release of carbon dioxide (CO<sub>2</sub>) from burning fossil fuels, along with other greenhouse gases, has become a significant contributor to global warming and climate change (Nunez, 2019). As a result, improving energy efficiency through the shift toward renewable energy is a crucial approach for reducing energy consumption and mitigating the negative impacts of carbon dioxide emissions on the environment (Torro et al., 2024; Chaudhry and Dudeja, 2023).

Globally, buildings account for approximately 36% of the world's total annual energy usage, with 22% of that energy consumption attributed to residential buildings (GlobalABC, 2019). The largest share of energy usage in residential buildings is used for lighting, heating, cooling, and air conditioning (Zidehsaraei et al., 2024). Therefore, enhancing energy efficiency in buildings and integrating renewable energy technologies while maintaining comfort and well-being for occupants are essential for addressing climate change and promoting sustainability (Hafez et al., 2023; Motlagh et al., 2024). In this context, utilizing free natural resources, such as natural ventilation, is a valuable solution that can be explored (Nejat et al., 2016; Shoara et al., 2024). Natural ventilation is a passive design method, and in general, it is a process that uses renewable energy, such as wind or buoyancy, to bring fresh air from outside to inside without the use of any mechanical systems (Ghulam et al., 2021). Many researchers aim to implement natural ventilation and passive cooling strategies to reduce energy consumption while ensuring thermal comfort and enhancing indoor air quality (IAQ) (Kosutova et al., 2019; Lukiantchuki et al., 2020; Pan et al., 2019). During the day, individuals spend approximately 80–90% of their time indoors, either working or living, which makes suboptimal air quality a significant factor

impacting their health, well-being, and productivity (Zomorodian et al., 2016; Lau et al., 2019). In addition to lowering a building's operational costs, natural ventilation can also reduce the size and expense of mechanical ventilation systems (Jomehzadeh et al., 2020).

Broadly, there are four primary strategies for natural ventilation: cross-ventilation, stack ventilation, mixed-mode ventilation, and single-sided ventilation (Izadyar et al., 2020). Given the nature of modern urban construction and the competition for optimal access to natural light in buildings, single-sided ventilation, which involves the presence of only one opening in the room, is the most commonly employed method in residential buildings (Liu et al., 2008).

In single-sided ventilation, airflow is primarily driven by the effects of buoyancy and wind pressure (Zhang et al., 2021). When the doors between rooms are closed, the potential for air exchange between them is significantly diminished, making ventilation through the single opening the sole available pathway (Dae-meii et al., 2019). Modern architectural practices employ various design elements, such as ventilation grilles, wind catchers, solar chimneys, integrated facade systems, windows, and wing walls, to facilitate different types of natural ventilation, including single-sided ventilation in buildings (Izadyar et al., 2020).

Wing walls are architectural elements that typically protrude from the surface of a building and are positioned either on both sides of an opening or between two openings, with the difference in wind pressure between the wind-facing and leeward surfaces enhancing the efficiency of airflow into the room (Chungloo and Tienchutima, 2011). In terms of implementation, wing walls, as non-load-bearing elements that can only support their own weight and the wind pressure acting on their surfaces, generally extend no more than 1.5 meters from the exterior wall, as longer extensions require specific structural justification (Buildings Department, 2019).

In single-sided ventilation without wing

walls, air velocity near the openings is high, but it decreases significantly as the distance from the openings increases (Chungloo and Tienchutima, 2011). The addition of wing walls between wind-facing windows generates positive and negative pressures at the air inlet and outlet, thereby enhancing the airflow velocity in single-sided ventilation systems (Stabat et al., 2012). In 1962 and 1968, Givoni carried out wind tunnel tests on room models both with and without wing walls to assess their effect on natural ventilation. His findings revealed that incorporating wing walls in single-sided ventilation systems greatly enhanced indoor air circulation compared to setups lacking wing walls (Mak et al., 2005). Based on Givoni's results of the experiments, the indoor air velocity in a room with two openings and two wing walls was three times higher than in an identical room with the same openings but without wing walls (Chungloo and Tienchutima, 2011). In the following, previous research focusing on wing walls is reviewed.

In a study, (Chandra et al.1983) examined the airflow in a single-sided ventilated room with and without a wing wall and found that the presence of a wing wall significantly increases the speed of air entering the room. (Mak et al. 2005) showed that larger, perpendicular wing walls improve wind speed and indoor air velocity in single-sided ventilation, especially with wind directions between 40° and 60°. (Mak et al. 2007) found that wing walls improve natural ventilation by increasing air exchange and indoor air velocity, especially when the wing wall depth equals the window width and the wind angle is about 45°. They also showed 3D CFD simulations closely match experimental results. (Chungloo and Tienchutima 2011) used 3D simulations to compare ventilation from wing walls and balconies in a residential room. They found that wing walls (2–4 m thick) with openings spaced 2–4 m apart improved ventilation at wind angles of 30–75°. Balconies reduced ventilation by 40–55% except at 90°

wind direction. They recommend balconies only in well-ventilated, wind-facing areas. Tall buildings with right angles and wind-exposed corners had the best ventilation. (Kumar et al. 2015) used CFD to study airflow with perpendicular wing walls and found that wing walls deeper than 0.5 m don't significantly boost air entry speed. A 0.45 m deep wall, costing 25% of a 1.8 m deep wall, achieved 90% of its efficiency. They recommend matching wing wall height to the window for about 80% efficiency at lower cost. Adding a horizontal canopy in an inverted L shape increased airflow velocity by 9%. Nejat et al. (2016) showed that a two-sided windcatcher with wing walls angled at 30°, 45°, and 60° improves ventilation. Wind tunnel tests and CFD simulations agreed, with the 30° angle performing best, delivering 910 L/s of fresh air at 2.5 m/s wind speed. This design increased ventilation by 50% compared to conventional models and met ASHRAE 62.1 standards. (Ghadikolaie et al. 2020) studied single-sided ventilation with balconies in Malaysian residential buildings using CFD. They found balconies can improve ventilation in high-rises, but poor design may reduce airflow. Adding a wing wall with a 22.5° angle and specific depth increased indoor airflow and enhanced ventilation. (Prihatanti et al. 2021) showed that combining wing walls with pivot windows at 45° and 90° improved indoor air velocity, increasing it up to 5× in corner rooms and 7× in middle rooms, especially when wind was not directly aligned with openings. (Yi et al. 2023) found that optimized wing wall designs boost indoor wind speed and enhance year-round natural ventilation in classrooms with single-sided windows under varying wind conditions. (Elhaddad and Mahmoud .2024) showed that in poorly ventilated single-sided spaces, natural ventilation can be improved by first adding a second outlet window and then installing a wing wall on the inlet window. While previous research has provided valuable insights into the use of wing walls for enhancing single-sided ventilation, several gaps and

limitations remain. First of all, limited research has generally been conducted on the role of wing walls in improving natural ventilation in buildings. Second, the effectiveness of wing walls under varying wind directions is not yet fully understood (Mak et al., 2005). Third, a significant challenge in achieving sufficient ventilation in many buildings arises from their design, which frequently creates poorly ventilated areas. This issue is largely attributed to the inclusion of only one window on a single wall in these spaces (Elhaddad and Mahmoud, 2024). Furthermore, there is a lack of sufficient research on optimizing the number and spacing of windows in conjunction with wing walls to improve natural ventilation. Finally, while existing studies emphasize the importance of wing walls in enhancing ventilation in single-sided rooms, there is a lack of sufficient investigation into the optimal depth, angle, and orientation of wing walls relative to wind direction (Ghadikolaei et al., 2020). These gaps highlight the importance of further research to optimize wing wall designs and integrate them effectively with other ventilation strategies. This study aims to optimize average indoor air velocity by incorporating a wing wall into the window design of a room with single-sided ventilation. Accordingly, the research focuses on the design parameters of windows with wing walls. To identify the optimal depth, angle, and position of the wing wall, the ventilation effectiveness of various wing walls with multiple depths (0.5, 1, and 1.5 meters) and angles (15°, 22.5°, 30°, and 45°) is analyzed. A key innovation of this study is the simultaneous investigation of the wing wall's depth and rotational angles (i.e., the application of a movable wing wall) to enhance ventilation efficiency and air velocity.

## **MATERIALS AND METHODS**

### **Computational Fluid Dynamics (CFD)**

The aim of the research is to investigate the appropriate depth and direction of wing walls with the same height as windows in single-sided

ventilation, their performance in relation to different wind directions, and the comparison between fixed and movable wing walls in such scenarios. For this purpose, modeling was conducted using Computational Fluid Dynamics (CFD). To validate the CFD model used in the present study, numerical data were compared with experimental data obtained from previous studies (Mak et al., 2005; Mak et al., 2007; Kumar et al., 2015).

Butterfly software (version 0.0.05), an advanced professional tool for environmental studies, was employed for CFD simulation. Butterfly is a Grasshopper/Dynamo plugin environment developed as a Python library. This tool was created using the object-oriented Python programming language. Butterfly performs CFD simulations using the OpenFOAM engine, which is currently the most reliable CFD engine, capable of running advanced simulation models and turbulence models (ranging from simple RAS to complex LES). Butterfly offers a simple and user-friendly interface for quickly building geometries and transferring them to OpenFOAM. The advantages of Butterfly include outdoor simulations for modeling urban wind patterns, wind flow-based simulations, and indoor buoyancy simulations for analyzing thermal comfort range and ventilation efficiency (Ladybug Tools, 2024).

The accuracy of airflow predictions in CFD simulations relies on the chosen boundary/initial conditions, turbulence model, and calculation method. The three primary turbulence models, listed from lowest to highest in terms of accuracy and computational expense, are: Reynolds-averaged Navier-Stokes (RANS), Large Eddy Simulation (LES), and Direct Numerical Simulation (DNS). Considering the capabilities of the computer software and hardware available, DNS was deemed the most appropriate for analyzing the sample room. However, DNS is not suitable for simulating natural ventilation in large-scale buildings, as was the case until the 1970s before the advent of high-speed comput-

ers (Rodrigues et al., 2021). In this method, the Navier-Stokes equations are solved numerically without any turbulence model. The cost of this simulation is directly related to the cube of the Reynolds number. For this reason, even at low Reynolds numbers, the computational cost of DNS is very high, making it impractical for high Reynolds numbers. In such cases, compressible RANS turbulence models, particularly the Renormalization Group k-epsilon (RNG k-epsilon) turbulence model from the standard k-epsilon turbulence model group, are used for compressible flow simulations. In a study conducted by Tominaga and Stathopoulos (2010), the flow and dispersion of pollutants around a cubic structure were analyzed using four k-epsilon turbulence models, including the standard k-epsilon model, the RNG k-epsilon model, the Launder and Spalding (1983) modified k-epsilon model, the Kataoka and Mizuno (2002) model, and finally the Realizable k-epsilon model. It was concluded that, in general, the RNG k-epsilon model is more consistent with experimental data and is the most accurate turbulence model.

In this study, a modeled room with single-sided ventilation and proposed window settings featuring wing walls was simulated as a variable in Butterfly, and the performance of internal ventilation was investigated.

#### Geometry

To investigate natural ventilation and achieve optimal wind speed, simulations were conducted for a residential room with single-sided ventilation. The room had default dimensions of 4 m by 5 m with a height of 3 m, serving as the sample space. The window was designed with a height of 1.5 meters and a width of 2 meters, positioned 1 meter above the floor. The specific dimensions and window placement in the simulation of a residential room with single-sided ventilation were chosen to reflect common residential settings and align with previous studies to optimize natural ventilation performance. The window to wall ratio (WWR) was set at 0.25. Setting the WWR to 0.25 is a compromise

that aims to achieve energy efficiency, indoor air quality, thermal comfort, and effective natural ventilation (Alwetaishi and Benjeddou, 2021; Hassieb et al., 2024; Wei et al., 2024). Figure 1 shows the physical model used for the computer simulation.

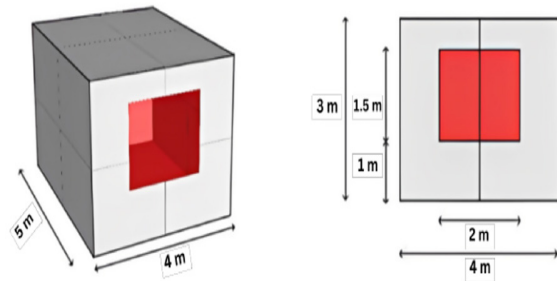


Figure 1: Physical model for the computer simulation

#### Numerical Grids, Discretization Scheme, Turbulence Model, and Boundary Conditions

In this study, the Butterfly CFD package is employed to simulate natural ventilation by solving the conservation equations for mass, momentum, and energy through the finite volume method. Turbulence was modeled with the RNG k- $\epsilon$  model turbulence model, which is effective for handling high strain rates and airflow around complex geometries. The load mesh component in Butterfly was determined to contain 39,896 cells. The mesh was generated using Butterfly CFD, which is based on OpenFOAM. This tool ensures compliance with standard mesh quality metrics, including skewness, orthogonality, and aspect ratio. The computational grid consisted of a total of 39,896 cells, with refinements near critical regions, such as windows and wing walls, to accurately capture airflow patterns. Given the robust meshing capabilities of Butterfly CFD, the generated mesh was deemed adequate for the purposes of this study (Ladybug Tools, 2024). The dimensions of the wind tunnel are  $34 \times 60 \times 15$ . Figure 2 illustrates the grid used for the simulated model.

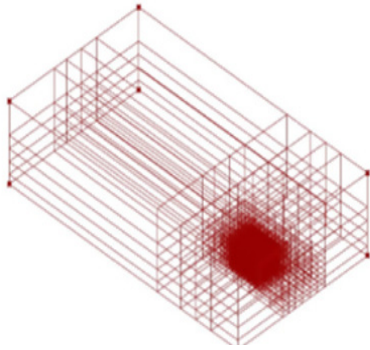


Figure 2: Grids of the simulation model

Since the main objective of the study was to implement the results in a city with low wind speed, such as Rasht, the default wind speed was set to 2.87 meters per second, representing the average wind speed in this city. In the modeling, the wind direction was kept constant, blowing from the north (geographic zero degrees). The model rotates relative to the wind, altering the angle of the incoming wind to the window.

Table 1 presents the test cases, including the position of the window and its angle to the wind flow, examined under various wind angles. The wind direction is consistently presumed to be fixed from the north ( $0^\circ$ ), and the cases under study are rotated to face the wind at seven various angles ( $0^\circ$ ,  $30^\circ$ ,  $60^\circ$ ,  $90^\circ$ ,  $120^\circ$ ,  $150^\circ$ , and  $180^\circ$ ). This rotation alters the angle of the incoming wind towards the window. The cases are categorized into four color-coded groups in the table, each representing a specific configuration of openings and wing walls in the room, as previous research [9,21,24-26,40-44] (Nejat et al., 2016; Chungloo and Tienchutima, 2011; Mak et al., 2005; Elhaddad and Mahmoud, 2024; Ghadikolaie et al., 2020; Chandra et al., 1983; Mak et al., 2007; Kumar et al., 2015; Prihatanti et al., 2021; Yi et al., 2023):

- Green Section (Cases 1–3): In this section, the openings are without wing walls to examine the natural airflow pattern inside without the influence of wing walls. The number and placement of windows are determined to achieve the maximum indoor air velocity for subsequent analysis.

- Gray Section (Cases 4 and 5): Building upon the results of the previous section, wing walls are added. Cases 4 and 5 examine the number of wing walls for each window to identify the optimal configuration for maximizing indoor air velocity.

- Orange Section (Cases 6–8): This section investigates the depth of the wing walls based on the findings from the previous section.

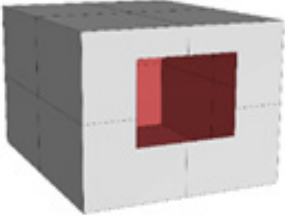
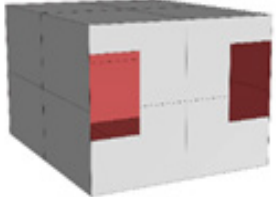
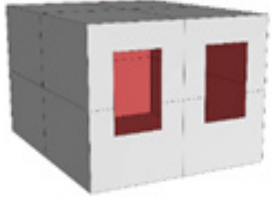
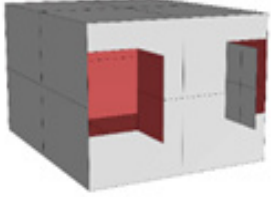
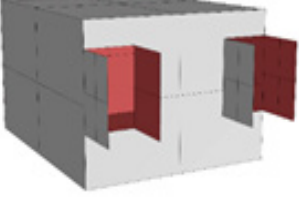
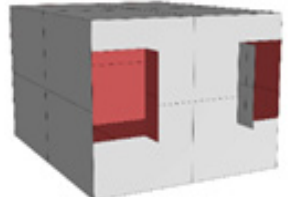
- Blue Section (Case 9): Since wind direction is not always constant in a building, a movable wing wall is evaluated in Case 9. This configuration offers greater flexibility and control compared to fixed wing walls (reference if needed). The goal is to assess the maximum impact of the wing wall on enhancing indoor airflow velocity.

Table 2 provides a complete description of all 9 cases listed in Table 1 across two columns. One column represents the specifications of each room, including the number of windows, the window-to-wall ratio, and the number of wing walls. The other column illustrates the 3D model of each case.

**Table 1:** Different angles of window against wind flow in cases 1 to 9 (Wind direction constant from North)

Wind Direction	0°	30°	60°	90°	120°	150°	180°
Case 1							
Case 2							
Case 3							
Case 4							
Case 5							
Case 6							
Case 7							
Case 8							
Case 9							

**Table 2:** Physical configuration of the 3D room model for nine cases

<p><b>Case 1</b></p>	<p>Case 1: One window, WWR = 0.25 (ratio of window to wall 3 to 12), no wing wall.</p>	
<p><b>Case 2</b></p>	<p>Case 2: Two windows in the corner of the room, WWR = 0.25, the distance between the two windows = 2 meters, no wing wall.</p>	
<p><b>Case 3</b></p>	<p>Case 3: Two windows in the middle, WWR = 0.25, distance between the two windows = 1 meter, no wing wall.</p>	
<p><b>Case 4</b></p>	<p>Case 4: Two windows in the corner, WWR = 0.25 (ratio of window to wall 3 to 12), the distance between the two windows = 2 meters, 2 wing walls with a depth equal to the width of the windows.</p>	
<p><b>Case 4</b></p>	<p>Case 5: Two windows in the corner, WWR = 0.25 (ratio of window to wall 3 to 12), the distance between the two windows = 2 meters, 4 wing walls with a depth equal to the width of the windows.</p>	
<p><b>Case 5</b></p>	<p>Case 6: Two windows in the corner, WWR = 0.25 (ratio of window to wall 3 to 12), distance between two windows = 2 meters, 2 wing walls with a depth of half of the width of the windows.</p>	

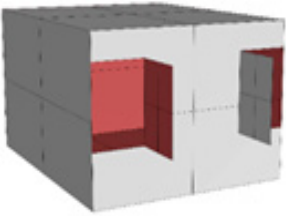
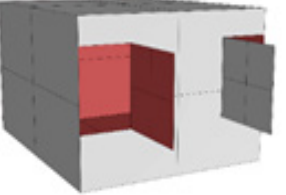
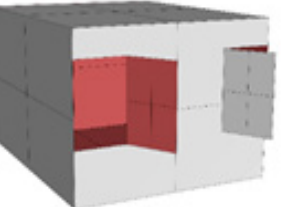
<b>Case 6</b>	Case 7: Two windows in the corner, WWR = 0.25 (ratio of window to wall 3 to 12), distance between two windows = 2 meters, 2 wing walls with a depth equal to the width of the windows.	
<b>Case 7</b>	Case 8: Two windows in the corner, WWR = 0.25 (ratio of window to wall 3 to 12), distance between two windows = 2 meters, 2 wing walls with a depth of 1.5 times the width of the windows.	
<b>Case 8</b>	Case 9: Two windows in the corner, WWR = 0.25 (ratio of window to wall 3 to 12), distance between two windows = 2 meters, with 2 angled or movable wing walls.	

Figure 3 provides a summarized depiction of the simulation process in this study.

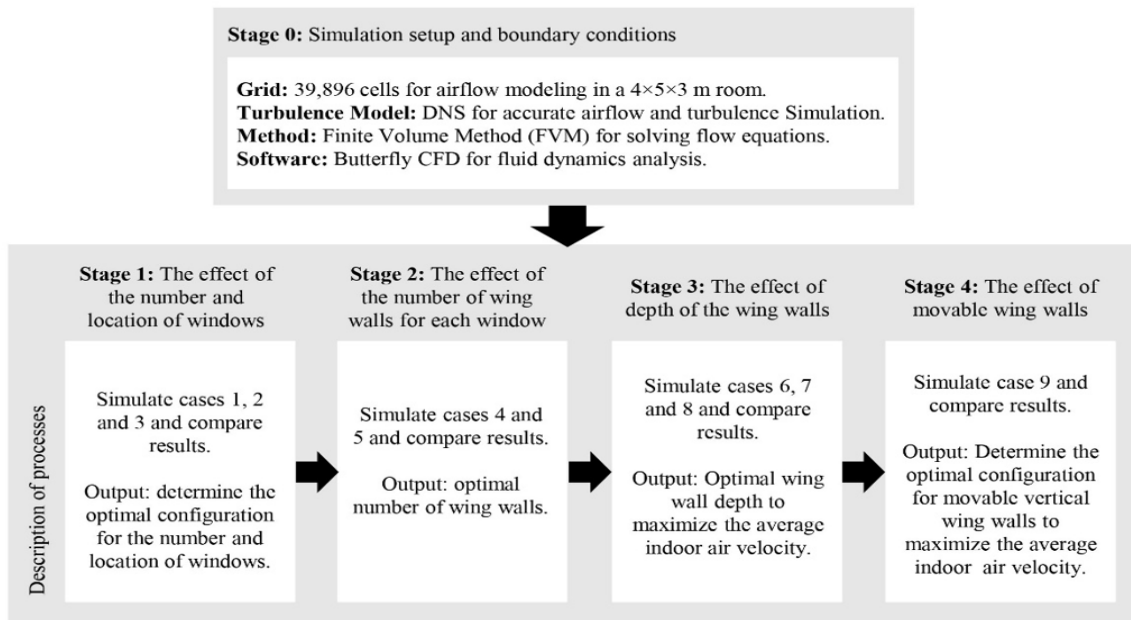


Figure 3: The simulation process

## DISCUSSION AND FINDINGS

### *The Effect of the Number and Location of Windows*

The first step is to determine whether single-sided ventilation of the room requires one window or two. If two windows are necessary, the next question is: what should the distance between them be? To address this, we consider cases 1, 2, and 3. Each scenario is simulated with 30-degree rotations to evaluate the accuracy of the results at different angles of the building relative to the wind direction. After simulating the cases and calculating the average indoor air velocity (expressed as a percentage of the inlet velocity), the results for angles ranging from 0 to 180 degrees are presented in Figure 4.

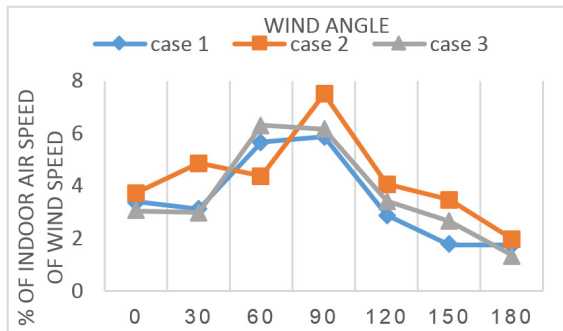


Figure 4: : The effect of the number and location of the window without wing walls (cases 1,2 &3)

According to Figure 4, Using two windows with the same total area is more effective than one window for single-sided ventilation of the room. The results also indicate that positioning two windows at the corners of the room, with a greater distance between them, performs better across a wider range of wind angles compared to placing two windows closer together. This configuration enhances ventilation and increases the airflow inside the room. In other words, cases 2 and 3 outperform case 1. Furthermore, case 2 shows better performance across a wider range of wind angles than case 3.

### *The Effect of the Number of Wing Walls for Each Window*

Based on the results of the first stage, two win-

dows positioned in the far corners are selected. In the second stage, to evaluate the impact of the number of perpendicular wing walls for each window on the indoor air velocity, cases 4 and 5 are analyzed. Finally, these two cases are compared with case 2. After performing the simulations and calculating the average indoor air velocity (expressed as a percentage of the inlet velocity), the results for angles ranging from 0 to 180 degrees are presented in Figure 5.

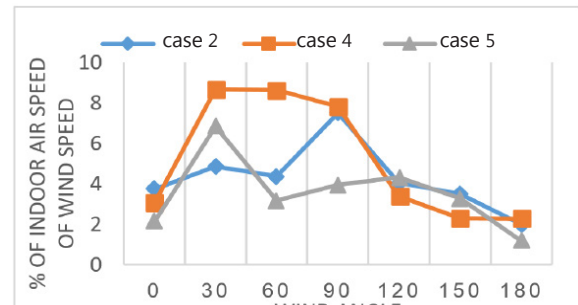


Figure 5: The effect of the Number of Wing Walls for Each Window (cases 2,4 & 5)

According to Figure 5, at a zero-degree angle, the use of wing walls decreases the average indoor air velocity. The results also indicate that adding a single perpendicular wing wall to each window, rather than two, significantly improves the average indoor air velocity. For angles greater than 120 degrees, similar to the zero-degree angle, the presence of wing walls reduces air velocity and ventilation. In other words, case 4 outperforms case 5. Additionally, case 4 demonstrates better performance compared to case 2. Therefore, for subsequent stages, a room with two windows, each equipped with one wing wall, is selected.

### *The Effect of Depth of the Wing Walls*

The third stage aims to determine the optimal depth of the perpendicular wing wall based on the ratio of the window opening's width. For this purpose, three depths were considered: half the width, equal to the width, and 1.5 times the width of the window, corresponding to cases 6, 7, and 8. After conducting simulations and calculating the average indoor air velocity (expressed as a percentage of the inlet velocity), the

results for angles ranging from 0-180 degrees are presented in Figure 6.

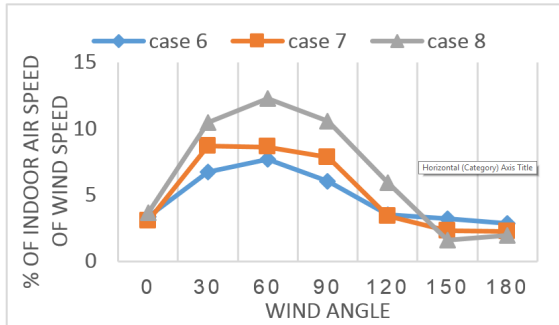


Figure 6: The effect of Depth of the Wing Walls (cases 6,7 & 8)

According to Figure 6, the average indoor air velocity increases as the depth of the wing wall increases. In other words, Case 8 outperforms Case 7, and both perform better than Case 6. Therefore, a wing wall depth equal to the width of the window is considered optimal, as supported by previous research. However, it should be noted that the maximum depth of the wing wall is constrained by the technology used in their construction, aesthetic considerations, and architectural performance criteria.

### The Effect of Movable Wing walls

Finally, the perpendicular wing walls are made movable to assess their impact on enhancing ventilation and increasing air velocity. Four different scenarios for the rotation direction of the wing walls are simulated, as outlined in Table 3, to identify the optimal rotation option for case 9.

Table 3: Four different conditions for the direction of rotation of the wing walls (Alternatives to case 9)

Condition 1	Condition 2	Condition 3	Condition 4

The results indicate that the second condition is the optimal choice for rotating wing walls, providing the highest increase in both airflow speed and volume within the room (see Figure 7). Consequently, the rotation of the wing walls is based on the second condition and is simulated at four angles of rotation: 15°, 22.5°, 30°, and 45°. These are then compared with the fixed perpendicular wing wall configuration.

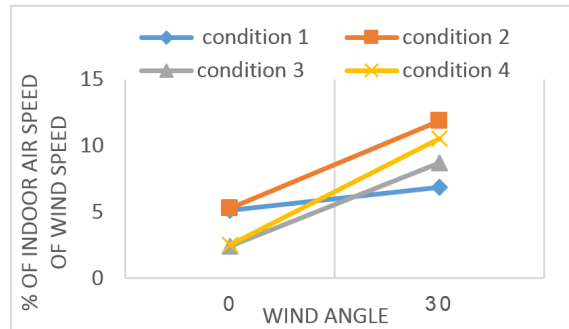


Figure7: The results of different conditions of the wing walls rotation

According to Figure 8, the simulation results reveal that at a zero-degree angle, movable wing walls improve ventilation and increase the average indoor air velocity, unlike fixed perpendicular wing walls. Movable wing walls outperformed fixed perpendicular wing walls for wind angles greater than 0° and less than 90° at rotations of 15°, 22.5°, and 30°. At a 45° rotation, there was a positive effect for wind angles between 0° and 30°, but an inverse effect for angles between 30° and 75°. For wind angles from 75° to 120°, the fixed perpendicular wing walls demonstrated superior performance. However, for wind angles ranging from 120° to 180°, movable wing walls showed better performance than their fixed counterparts. In summary, case 9 at rotations of 15°, 22.5°, and 30° outperforms case 7.

Overall, the superior performance of wing walls or oblique retaining walls is confirmed in terms of increasing average indoor air velocity, enhancing ventilation, and potentially reducing energy consumption compared to fixed perpendicular wing walls.

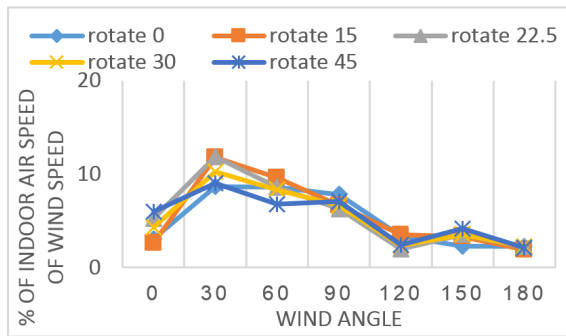


Figure 8: The Effect of Movable Wing Walls

## RESULT AND CONCLUSION

The purpose of this study was to increase the average indoor air velocity in a single-sided ventilated room by incorporating a wing wall. Therefore, the study investigated the configuration parameters of a window with a wing wall. To achieve this, the ventilation performance of several wing walls with varying depths (0.5, 1, and 1.5 meters) and angles (15°, 22.5°, 30°, and 45°) was analyzed to determine the optimal depth, angle, and location of the wing wall.

The findings of the study demonstrate that using two windows with the same total area in single-sided ventilation is more effective than using one window, as it improves both ventilation efficiency and the indoor air velocity. Enhancing the design further, the addition of a perpendicular wing wall to one side of each window contributes to increased airflow and higher average indoor air velocity. Moreover, increasing the depth of the wing wall leads to even better ventilation performance, with the optimal depth found to be equal to the width of the window. Notably, movable wing walls angled at 15°, 22.5°, and 30° outperform fixed perpendicular wing walls by providing superior ventilation and greater indoor air velocity.

Consistent with previous research (Chandra et al., 1983), this study also demonstrated that the presence of a wing wall significantly increases the speed of air entering the room. In addition, this study, similar to previous research (Yi et al., 2023), indicates that optimized wing wall designs can significantly enhance indoor wind speed and improve natural ventilation in a room with one-sided windows. This study

also revealed that adding a second window to a single wall with the installation of a wing wall can effectively facilitate natural ventilation, as previously shown in earlier research (Elhaddad and Mahmoud, 2024).

Furthermore, previous research has demonstrated the effectiveness of incorporating wing walls into windows (Mak et al., 2005; Mak et al., 2007) and balconies (Chungloo & Tienchutima, 2011; Ghadikolaie et al., 2020) in enhancing natural ventilation in single-sided ventilation configurations. Consistent with these findings, the results of the present study confirm that the integration of wing walls with windows significantly improves airflow within spaces reliant on single-sided ventilation.

Moreover, the study's findings align with prior research (Mak et al., 2005; Mak et al., 2007; Kumar et al., 2015; Ghadikolaie et al., 2020) in establishing that an increase in the depth of wing walls enhances natural ventilation and elevates indoor air velocity. In this context, the optimal depth for the wing wall was determined to be equivalent to the width of the window. The optimal wind direction angle identified in this study, ranging between 30° and 60°, also corroborates previous findings suggesting optimal angles of 40°–60° (Mak et al., 2005), 30°–75° (Chungloo & Tienchutima, 2011), 30° (Nejat et al., 2016), and 45° (Prihatanti et al., 2021).

In addition, the positive influence of rotating wing walls at a 22.5° wind angle, as highlighted by Ghadikolaie et al. (2020), was validated in this study. Further analysis of additional angles (15°, 30°, and 45°) revealed that positive ventilation effects are achieved at 15°, 22.5°, and 30°, whereas a negative impact is observed at 45°.

Finally, this study fills gaps in existing research by thoroughly examining the effects of window configurations, wing wall depths, and movable wing walls on single-sided ventilation performance. Unlike prior studies that mainly focused on fixed wing walls or isolated factors, this research explores the comparative impact of using one versus two windows, demonstrating that two windows significantly improve air velocity. It also identifies the optimal depth of wing walls relative to window width, expanding upon earlier studies that primarily considered

fixed depths. Additionally, the study investigates the effects of movable wing walls at various angles (15°, 22.5°, 30°, and 45°), a topic that has received limited attention in previous literature. These findings offer a fresh perspective on designing windows equipped with movable and adaptable wing walls to enhance natural ventilation and energy efficiency.

Despite these valuable findings, the study faced certain limitations. The use of simulations instead of real wind tunnel experiments was a key limitation, driven by high costs and limited access. Additionally, the scarcity of existing literature on wing walls posed challenges, highlighting the need for further research on the topic.

For future studies, research on the effects of awnings and various types of openings on wing walls, the performance of movable wing walls at different heights in high-rise buildings, smart wing walls, the comparative effects of fixed perpendicular wing walls and movable wing walls on adjacent rooms, and the impact of movable wing walls on cross ventilation is recommended.

## REFERENCES

- Alwetaishi, M., & Benjeddou, O. (2021). Impact of window to wall ratio on energy loads in hot regions: A study of building energy performance. *Energies*, 14(4), 1080.
- Buildings Department. (2019). *Green and innovative buildings*. The Government of the Hong Kong Special Administrative Region. <https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/joint/JPN01.pdf>
- Chandra, S., Fairey, P., Houston, M., & Kerestecioğlu, A. A. (1983). Wingwalls to improve natural ventilation: Full-scale results and design strategies.
- Chaudhry, A., & Dudeja, G. (2023). Total factor efficiency of energy and carbon emissions in 18 Asian countries: An empirical assessment. *Journal of Asian Energy Studies*, 7, 77-90.
- Chungloo, S., & Tienchutima, C. (2011). The effect of wing-walls and balcony on wind-induced ventilation in high-rise residential units. *Journal of Architectural/Planning Research and Studies (JARS)*, 8(1), 109-120.
- Daemei, A. B., Eghbali, S. R., & Khotbehsara, E. M. (2019). *Bioclimatic design strategies: A guideline to enhance human thermal comfort in Cfa climate zones*. *Journal of Building Engineering*, 25, 100758.
- Elhaddad, R., & Mahmoud, A. H. (2024). Improving natural ventilation design for spaces with windows on one side (single-sided ventilation) in Egypt using wing-wall. *Journal of Engineering Research*.
- Ghadikolaei, F. M., Ossen, D. R., & Mohamed, M. F. (2020). Effects of wing wall at the balcony on the natural ventilation performance in medium-rise residential buildings. *Journal of Building Engineering*, 31, 101316.
- Ghalam, N. Z., Farrokhzad, M., & Nazif, H. (2021). Investigation of optimal natural ventilation in residential complexes design for temperate and humid climates. *Sustainable Energy, Grids and Networks*, 27, 100500.
- GlobalABC. (2019). *Global status report for buildings and construction 2019: Towards a zero emissions, efficient and resilient buildings and construction sector*.
- Hafez, F. S., Sa'di, B., Safa-Gamal, M., Taufiq-Yap, Y. H., Alrifay, M., Seyedmahmoudian, M., Stojcevski, A., Horan, B., & Mekhilef, S. (2023). Energy efficiency in sustainable buildings: A systematic review with taxonomy, challenges, motivations, methodological aspects, recommendations, and pathways for future research. *Energy Strategy Reviews*, 45, 101013.
- Hassieb, M. M., Ragab, A., & Mohamed, A. F. (2024). Quantifying the influence of window-to-wall ratio (WWR) on indoor air quality and thermal comfort: Classroom study in hot arid climates. In *IOP Conference Series: Earth and Environmental Science*, 1396(1), 012025.
- Izadyar, N., Miller, W., Rismanchi, B., & Garcia-Hansen, V. (2020). A numerical investigation of balcony geometry impact on single-sided natural ventilation and thermal comfort. *Building and Environment*, 177, 106847.
- Jomehzadeh, F., Hussen, H. M., Calautit, J. K., Nejat, P., & Ferwati, M. S. (2020). Natural ventilation by windcatcher (Badgir): A review on the impacts of geometry, microclimate, and macroclimate. *Energy and Buildings*, 226, 110396.
- Kataoka, H., & Mizuno, M. (2002). Numerical flow computation around aeroelastic 3D square cylinder using inflow turbulence. *Wind and Structures*, 5(2\_3\_4), 379-392.
- Kosutova, K., van Hooff, T., Vanderwel, C., Blocken, B., & Hensen, J. (2019). Cross-ventilation in a generic

isolated building equipped with louvers: Wind-tunnel experiments and CFD simulations. *Building and Environment*, 154, 263-280.

Kumar, T. S., Chandrasekhar, J., Vasudevan, S. K., & Balachandran, A. (2015). An analysis of the effect of wing walls on natural ventilation. *Indian Journal of Science and Technology*, 8(17), 10-7485.

Ladybug Tools. (2024). Butterfly: A plugin for integrating OpenFOAM with Grasshopper. <https://www.ladybug.tools/butterfly.html>

Lau, S. S., Zhang, J., & Tao, Y. (2019). A comparative study of thermal comfort in learning spaces using three different ventilation strategies on a tropical university campus. *Building and Environment*, 148, 579-599.

Launder, B. E., & Spalding, D. B. (1983). The numerical computation of turbulent flows. In *Numerical prediction of flow, heat transfer, turbulence and combustion* (pp. 96-116). Pergamon.

Liu, X., Niu, J., Perino, M., & Heiselberg, P. (2008). Numerical simulation of inter-flat air cross-contamination under the condition of single-sided natural ventilation. *Journal of Building Performance Simulation*, 1(2), 133-147.

Lukiantchuki, M. A., Prata Shimomura, A., Marques da Silva, F., & Caram, R. M. (2020). Wind tunnel and CFD analysis of wind-induced natural ventilation in sheds roof building: Impact of alignment and distance between sheds. *International Journal of Ventilation*, 19(2), 141-162.

Mak, C. M., Cheng, C., & Niu, J. L. (2005). The application of computational fluid dynamics to the assessment of green features in buildings: Part 1: Wing walls. *Architectural Science Review*, 48(2), 121-134.

Mak, C. M., Niu, J. L., Lee, C. T., & Chan, K. F. (2007). A numerical simulation of wing walls using computational fluid dynamics. *Energy and Buildings*, 39(9), 995-1002.

Motlagh, A. A., Havaeji, S., Orangian, M., & Samadani, A. (2024). Achieving net-zero energy buildings: Analyzing and optimizing strategies using sensitivity analysis. *Journal of Asian Energy Studies*, 8, 51-67.

Nejat, P., Calautit, J. K., Majid, M. Z., Hughes, B. R., Zeynali, I., & Jomehzadeh, F. (2016). Evaluation of a two-sided windcatcher integrated with wing wall (as a new design) and comparison with a conventional windcatcher. *Energy and Buildings*, 126, 287-300.

Nunez, C. (2019, April). Fossil fuels, explained. *National Geographic*. <https://www.nationalgeographic.com/environment/article/fossil-fuels>

[com/environment/article/fossil-fuels](https://www.nationalgeographic.com/environment/article/fossil-fuels)

Pan, W., Liu, S., Li, S., Cheng, X., Zhang, H., Long, Z., Zhang, T., & Chen, Q. (2019). A model for calculating single-sided natural ventilation rate in an urban residential apartment. *Building and Environment*, 147, 372-381.

Prihatanti, N. A., Ekasiwi, S. N., & Defiana, I. (2021). Effects of pivot windows and wing walls on single sided natural ventilation in Rumah Susun (walk-up flat). *IPTeK Journal of Proceedings Series*, 6, 411-417.

Rodrigues Marques Sakiyama, N., Frick, J., Bejat, T., & Garrecht, H. (2021). Using CFD to evaluate natural ventilation through a 3D parametric modeling approach. *Energies*, 14(8), 2197.

Shoara, S., Mofidi Shemirani, S. M., Shahriari, S. K., & Zarabadi, Z. S. S. (2024). Observing Temperature Changes and Wind Speed Variations in an Urban Canyon of Shiraz at Different Heights Using CFD Simulation. *International Journal of Urban Management and Energy Sustainability*, 5(2), 124-137.

Stabat, P., Caciolo, M., & Marchio, D. (2012). Progress on single-sided ventilation techniques for buildings. *Advances in Building Energy Research*, 6(2), 212-241.

Tominaga, Y., & Stathopoulos, T. (2010). Numerical simulation of dispersion around an isolated cubic building: Model evaluation of RANS and LES. *Building and Environment*, 45(10), 2231-2239.

Torro, S., Rusdi, R., Manda, D., Saleh, S., Akib, H., Darmayanti, D. P., & Ardin, H. (2024). Assessing public awareness and stakeholder influence in renewable energy implementation: A case study from Sulawesi, Indonesia. *Journal of Asian Energy Studies*, 8, 95-109.

Wei, T. S., Nasir, M. H., Hassan, A. S., Basher, H. S., Nawi, M. N., & Mustapha, T. D. (2024). The influence of window-to-wall ratio (WWR) on airflow profile for improved indoor air quality (IAQ) in a naturally-ventilated workshop in a hot-humid climate. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 116(1), 139-157.

World Economic Forum. (2019). *World Economic Forum annual report 2019: Climate forecast: World is "sleepwalking into catastrophe."*

Yi, Y. K., Anis, M., Jang, K., & Kim, Y. J. (2023). Application of machine learning (ML) and genetic algorithm (GA) to optimize window wing wall design for natural ventilation. *Journal of Building Engineering*, 68, 106218.

Zhang, H., Yang, D., Tam, V. W., Tao, Y., Zhang,

G., Setunge, S., & Shi, L. (2021). A critical review of combined natural ventilation techniques in sustainable buildings. *Renewable and Sustainable Energy Reviews*, 141, 110795.

Zidehsaraei, M., Zidehsaraei, M., & Esfandiar, K. (2024). Do pro-environmental factors lead to customers' purchase intention of home energy management system? The moderating effects of energy-efficient habits. *Green and Low-Carbon Economy*. <https://ojs.bonviewpress.com/index.php/GLCE/article/view/2907>

Zomorodian, Z. S., Tahsildoost, M., & Hafezi, M. (2016). Thermal comfort in educational buildings: A review article. *Renewable and Sustainable Energy Reviews*, 59, 895-906.

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