Wind Engineering Joint Usage/Research Center
FY2025 Research Result Report

Research Field: Outdoor Environment
Research Year: FY2025
Research Number:
Research Theme: Optimizing Wing Wall Configurations for Enhanced Cross Ventilation in High-Density Apartment Buildings

Representative Researcher: Napoleon A. Enteria, PhD

Budget [FY2025]: 300,000.00 Yen

*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

1. Research Aim

This study aims to investigate the effectiveness of adding wing walls to multi-unit, multi-storey office and residential buildings through wind tunnel experiments and Computational Fluid Dynamics (CFD) analysis.

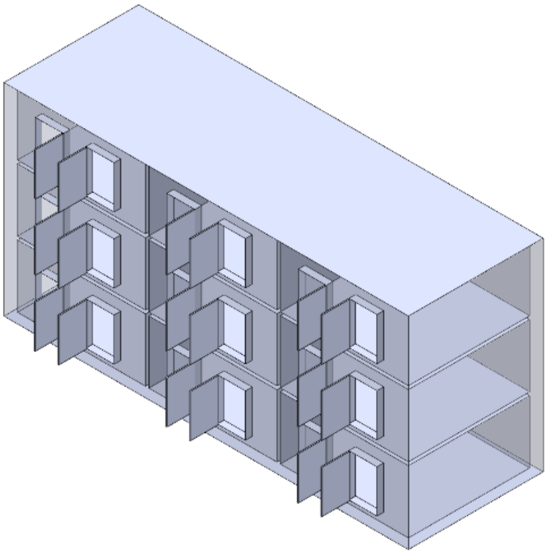


Figure 1. Multi-unit multi-storey building with wing walls.

2. Research Method

A three-storey building with three units per storey (3x3 building) is being investigated, both with and without wing walls, under varying wind directions and speeds. Since wind tunnel tests allow for 5% to 10% blockage ratio (Lee, 1977), this study modeled a building with 5.4% blockage ratio considering the area of wind tunnel to be used (shown in Figure 3).

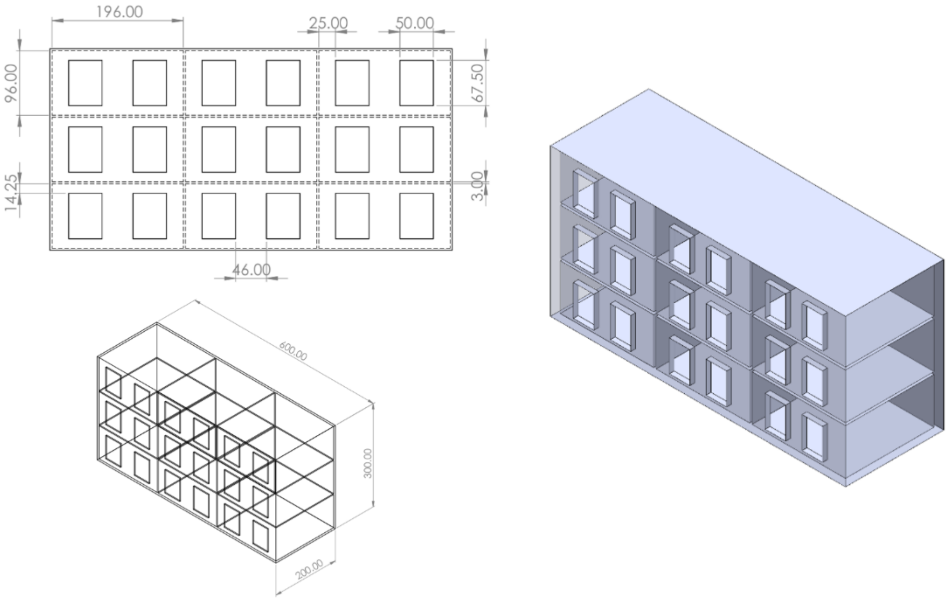


Figure 2. Modeled 3x3 single-sided ventilated building.

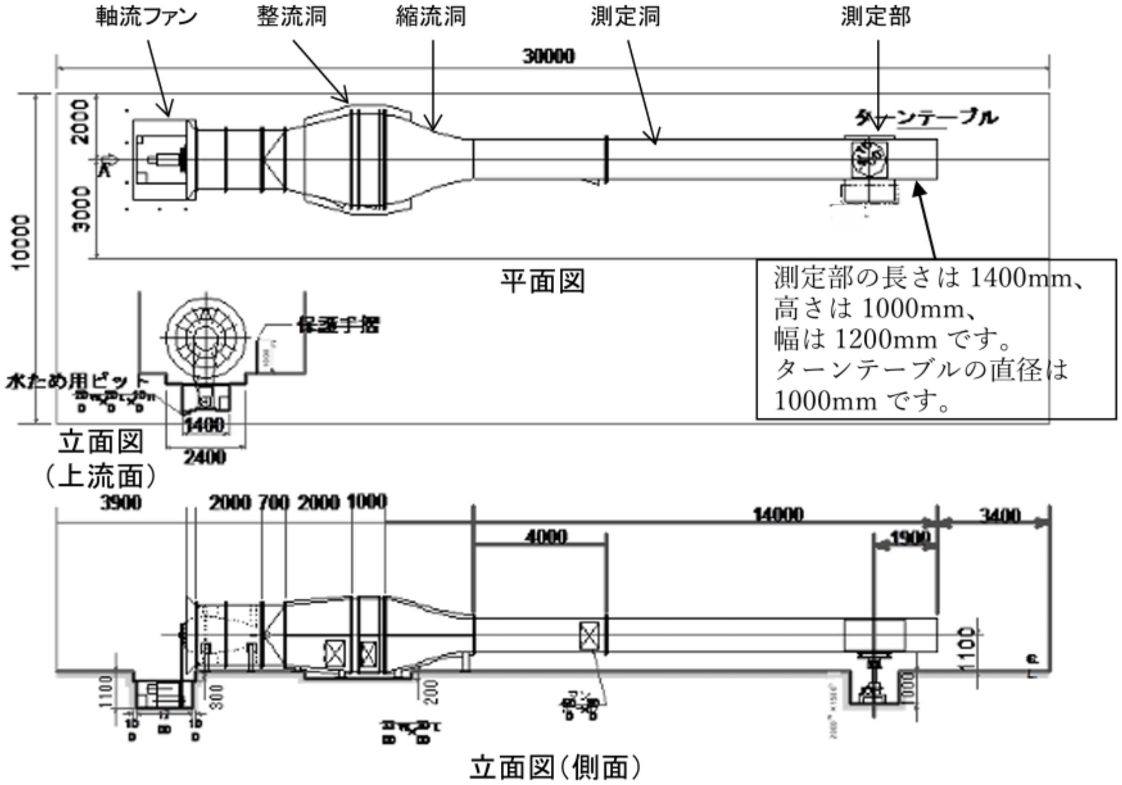


Figure 3. Wind tunnel plan and elevation view.

Wind Tunnel Experimentation

For the wind tunnel experiment, acrylic glass panels were used to fabricate the sample model of 3x3 building unit. Copper tubes were attached to serve as ports for tracer gas injection and sampling, connected via plastic tubing. To simulate and measure airflow and ventilation performance, the tracer gas method developed by Kono et. al (2007) was applied. Ethylene *(C_2H_4)* was selected as the tracer gas because it is easily detectable, non-reactive, and has a molecular weight similar to air. A gas supply and suction system was integrated into the model, allowing controlled release and collection of the tracer gas during testing.

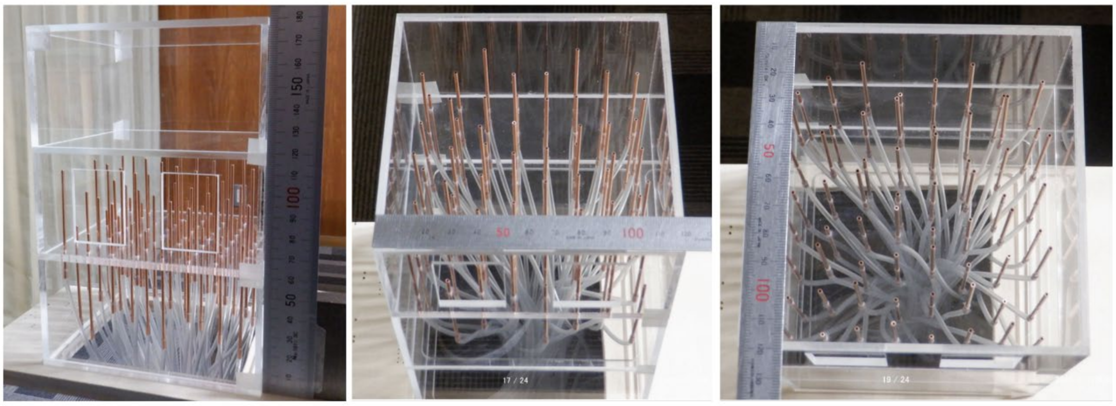
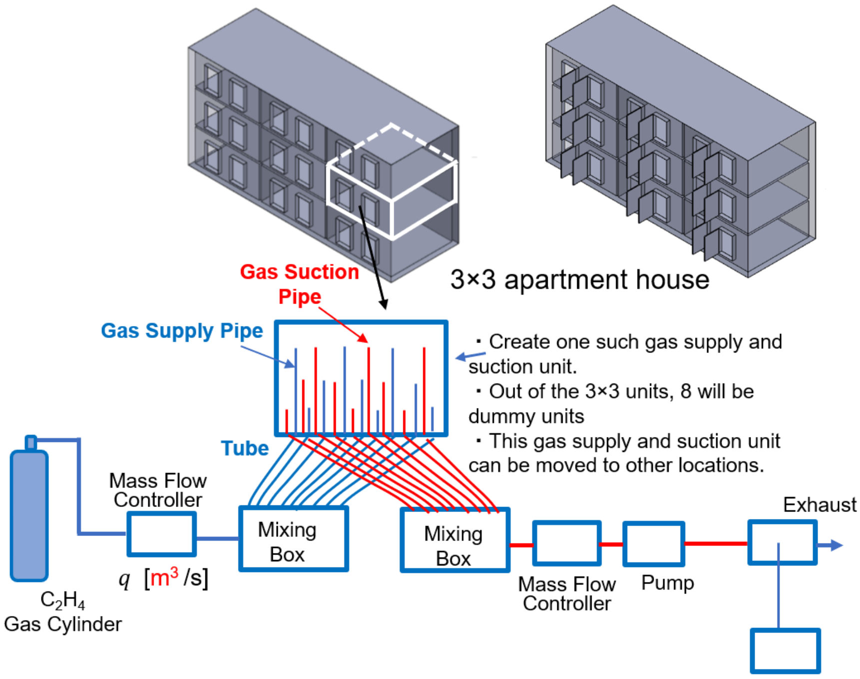


Figure 4. Fabricated 3x3 building model.



- Create one such gas supply and suction unit.
- Out of the 3×3 units, 8 will be dummy units
- This gas supply and suction unit can be moved to other locations.

Figure 5. Setup for tracer gas method.

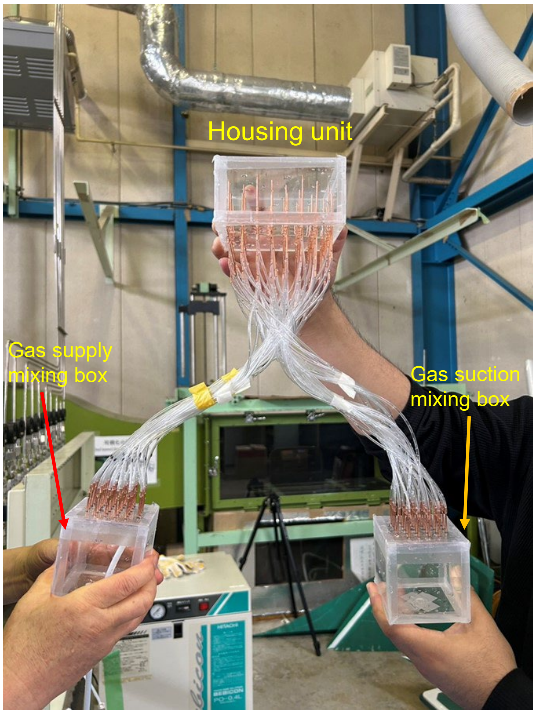


Figure 6. Fabricated building model equipped with gas supply and suction mixing boxes for tracer gas dispersion and sampling.

Figure 7. Gas supply station and mass flow controller.

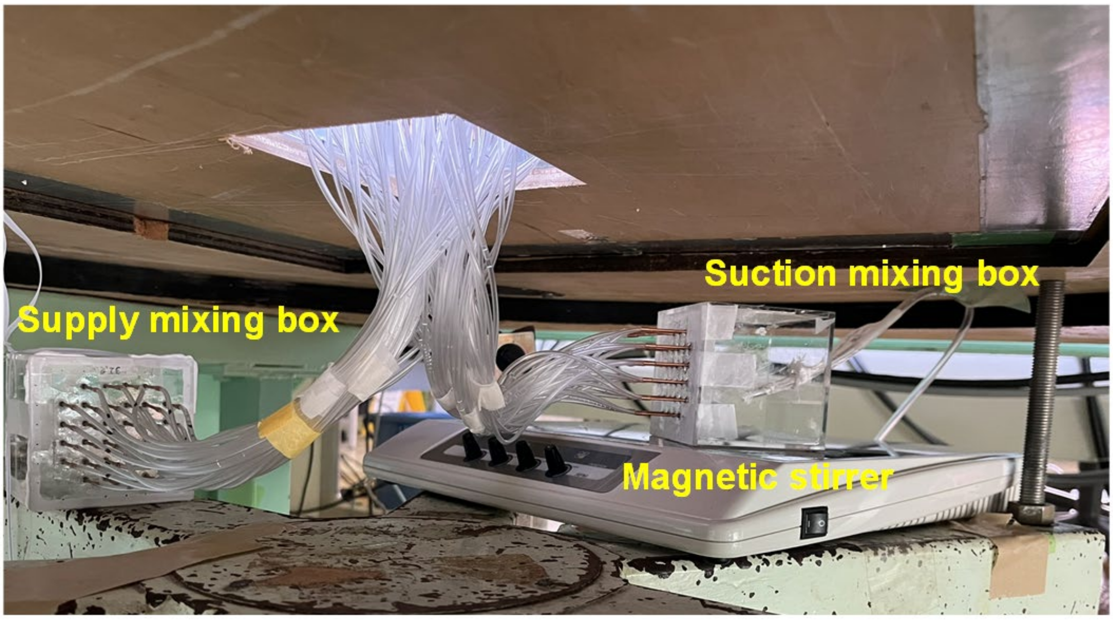


Figure 8. Mixing box setup under the wind tunnel floor.

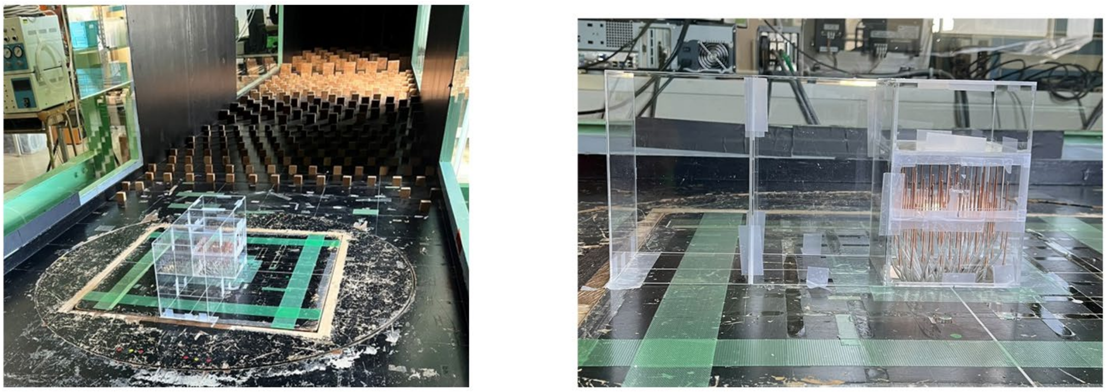


Figure 9. Model installation in the wind tunnel.

3. Research Result

The vertical distribution of the approaching flow in the wind tunnel was first measured to characterize the incoming wind profile. As shown in Figure 10, the experimental data closely followed a power law distribution with an exponent（α）of 0.25, indicating a moderately uniform flow typical of urban boundary layer conditions. The fabricated 3×3 building model was then subjected to three different wind directions: 0°, 45°, and 90°, as illustrated in Figure 11.

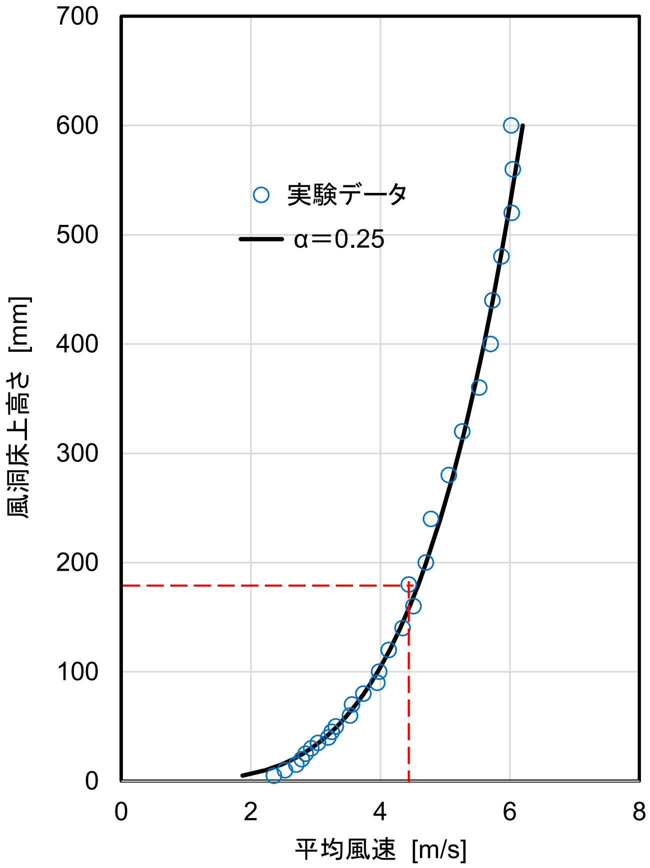


Figure 10. Wind velocity profile.

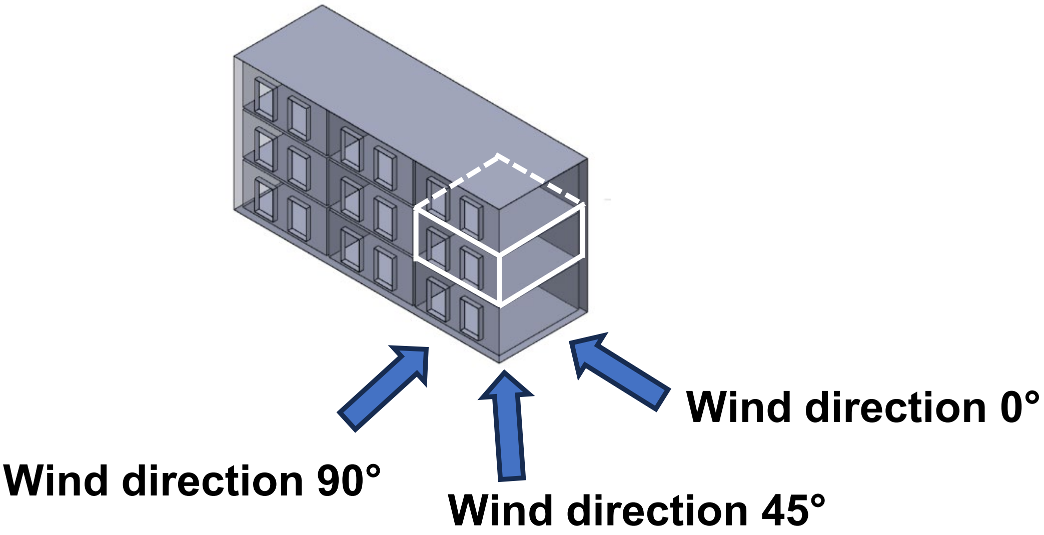


Figure 11. Schematic of wind directions approaching the 3x3 building model for ventilation testing.

Preliminary Result

A preliminary tracer-gas experiment was conducted to evaluate the windward-side unit located on the second level of the building at a 45° wind direction. The test was performed under varying reference wind speeds and gas emission rates to verify the consistency of the dimensionless concentration and normalized ventilation rate. The corresponding results are summarized in Table 1.

Table 1. Tracer Gas experimental preliminary result.

Case	Wind direction, θ [°]	Reference wind speed, U_h [m/s]	Gas emission rate [cc/min]	Gas emission rate [m^3/s]	Dimensionless concentration [-]	Normalized ventilation rate [-]
Case 1	45	4.4	203	3.4E−08	2.7E+01	0.038
Case 2	45	4.3	406	6.8E−08	2.6E+01	0.039
Case 3	45	1.8	406	6.8E−08	2.3E+01	0.043

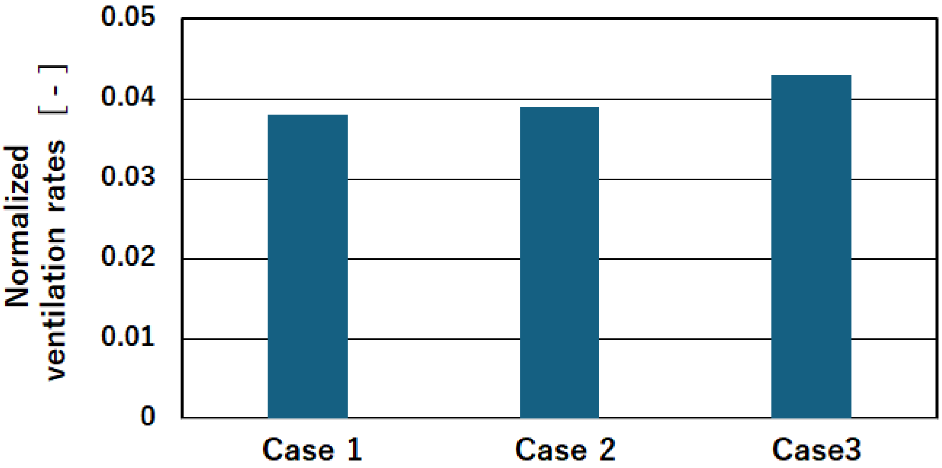


Figure 12. Comparison of normalized ventilation rate in the preliminary test cases.

The unit was tested under three reference wind speeds of 4.4 m/s, 4.3 m/s, and 1.8 m/s, with gas emission rates of 203 and 406 cc/min. As shown in Table 1 and Figure 12, the normalized ventilation rate remained relatively consistent across the three cases, ranging from 0.038 to 0.043. Similarly, the dimensionless concentration showed only a small variation despite changes in wind speed and gas emission rate. This suggests that the dimensionless concentration and normalized ventilation rate are appropriate indicators for comparing ventilation performance under varying experimental conditions. Therefore, the preliminary test supports the suitability of the tracer-gas experimental method for the succeeding ventilation analysis.

Experimental Result

After confirming the suitability of the dimensionless indicators and the appropriateness of the experimental method, the final tracer-gas tests were conducted. In this experiment, the building model was evaluated with and without wing walls under three wind direction: 0°, 45°, and 90°. The tests were performed at a constant reference wind speed of approximately 5 m/s, with the gas emission rate fixed at 420 cc/min. The evaluation focused on the four unit locations in the building: second-floor windward, central, and leeward-side units, as well as the third-floor windward-side unit, as shown in Figure 13.

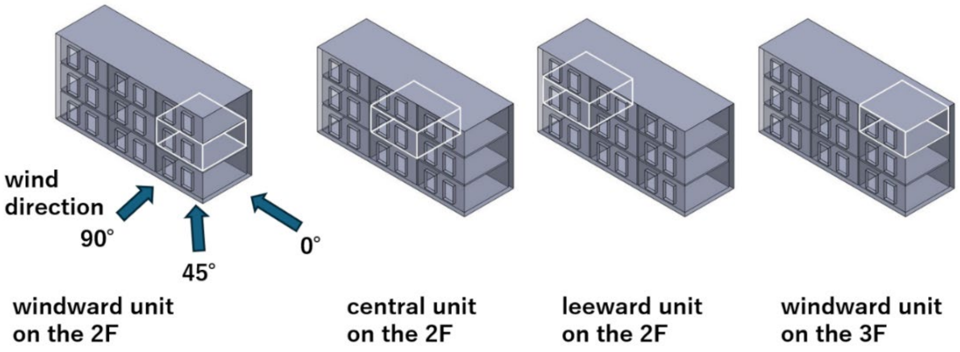


Figure 13. Selected test locations and wind directions in the 3x3 apartment building model.

For the second-floor windward-side unit, the normalized ventilation rate showed a substantial increase after the installation of wing walls at the 45° and 90° wind directions, as shown in Figure 14. At these wind directions, the ventilation rate approximately doubled compared with the case without wing walls. This suggests that the wing walls enhanced the wind-driven ventilation performance by redirecting the approaching airflow toward the window opening. However, at 0° wind direction, a slight decrease in the normalized ventilation rate was observed after the installation of wing walls, indicating that the effectiveness of wing walls depends on the incident wind direction.

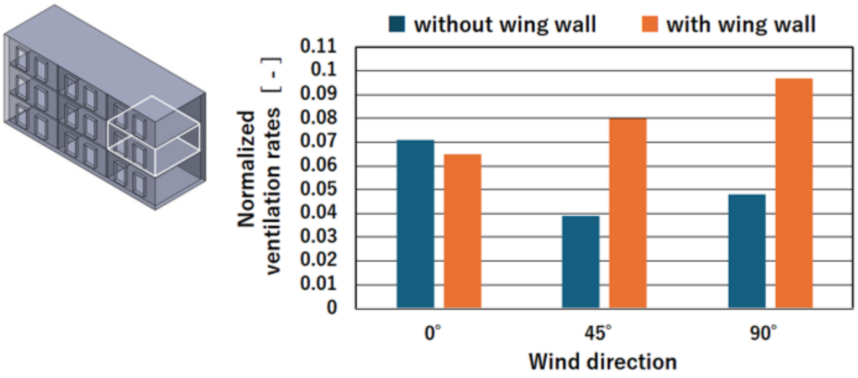


Figure 14. Comparison of the normalized ventilation rate of the second-floor windward unit with and without wing wall.

Meanwhile, for the second-floor central unit, the installation of wing walls increased the normalized ventilation rate at all wind directions, as shown in Figure 15. The increase was approximately 1.3 times at 0°, 2.7 times at 45°, and 1.7 times at 90° compared with the case without wing walls. The highest improvement was observed at 45°, suggesting that the wing walls were most effective when the incoming wind approached the building at an oblique angle. This may be attributed to the ability of the wing walls to redirect airflow toward the window opening and enhance the pressure difference across the unit. Overall, the results indicate that wing walls can improve the ventilation performance of the central unit, with their effectiveness varying depending on wind direction.

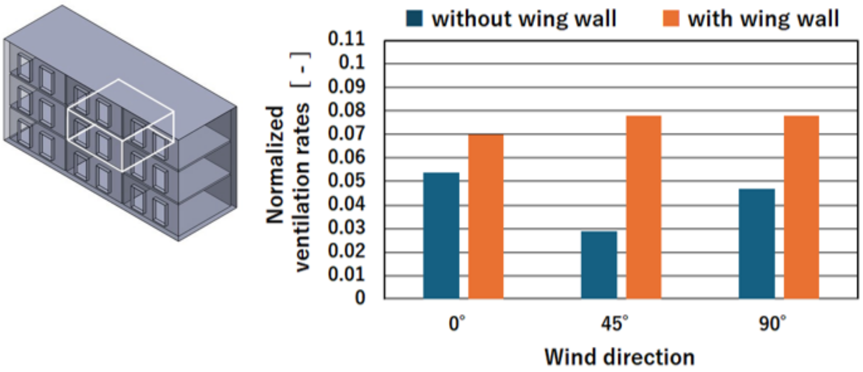


Figure 15. Comparison of the normalized ventilation rate of the second-floor central unit with and without wing walls.

For the second-floor leeward-side unit, the installation of wing walls also increased the normalized ventilation rate at all wind directions, as shown in Figure 16. The ventilation rate increased by approximately 2.7 times at 0°, 3.3 times at 45°, and 1.9 times at 90° compared with the case without wing walls. The greatest improvement was observed at 45°, indicating that the wing walls were most effective under oblique wind conditions. This suggests that the wing walls enhanced the airflow interaction around the building façade, which may have improved the pressure-driven ventilation of the leeward-side unit. Overall, the results show that the wing walls contributed to higher ventilation performance even in the leeward unit, although the magnitude of improvement varied depending on wind direction.

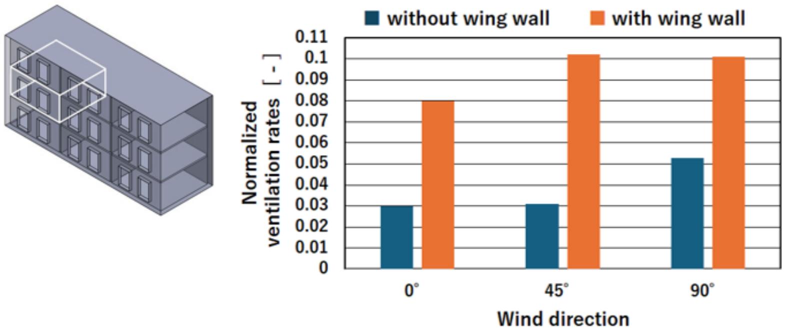


Figure 16. Comparison of the normalized ventilation rate of the second-floor leeward-side unit with and without wing walls.

On the other hand, for the third-floor windward-side unit, the effect of wing walls varied depending on wind direction, as shown in Figure 17. At 0° wind direction, where the airflow was parallel to the façade, the normalized ventilation rate decreased after the installation of wing walls. A similar trend was also observed in the second-floor windward-side unit, where ventilation performance was likewise better without wing walls at 0°. This suggests that when the wind flows parallel to the façade, the wing walls may interfere with or reduce the effective airflow entering the opening. However, at 45° and 90°, corresponding to oblique and normal wind directions, respectively, the normalized ventilation rate increased with the installation of wing walls. This indicates that the wing walls were more effective when the incoming airflow approached the façade obliquely or directly, as they may have redirected more air toward the window opening. Overall, the results show that the effect of wing walls on the ventilation performance of windward-side units is strongly dependent on wind direction.

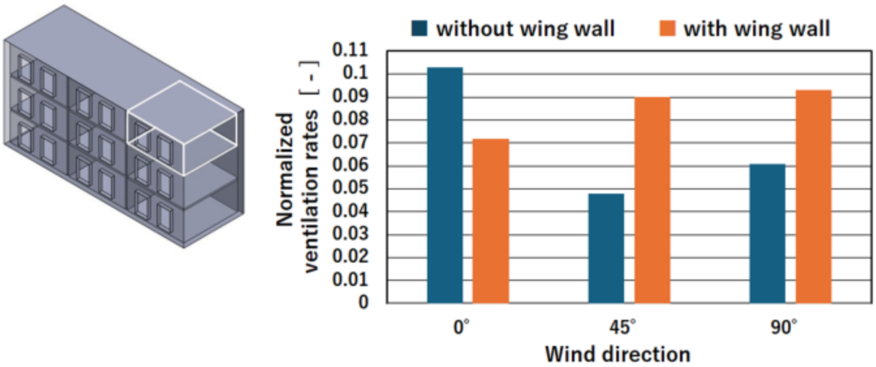


Figure 17. Comparison of normalized ventilation rate of the third-floor windward-side unit with and without wing walls.

To assess whether the placement of wing walls on adjacent units affects the ventilation of the target unit, an additional case was performed with wing walls installed on all nine units of the building model. In this case, the second-floor central unit was evaluated under the same wind directions used in the preceding tests. As shown in Figure 18, the installation of wing walls increased the normalized ventilation rate, particularly at 45° and 90° wind directions, with the highest ventilation rate observed at 45°. This indicates that wing walls remained effective under oblique and normal wind directions even when installed across all units. Compared with the case where wing walls were installed only on the target unit, the ventilation performance was generally similar at 45° and 90°, suggesting that the ventilation rate was mainly governed by the local airflow near the opening. However, at 0° wind direction, the normalized ventilation rate was slightly lower when wing walls were installed on all nine units than when they were installed only on the target unit. This may be attributed to the upstream wing walls partially obstructing or disturbing the incoming parallel airflow, thereby reducing the amount of air reaching the target dwelling.

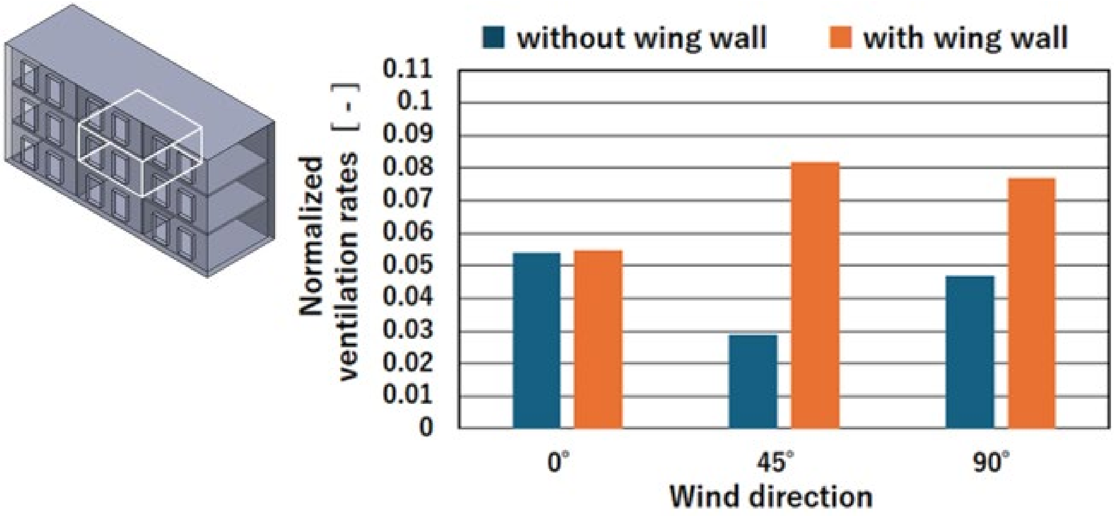


Figure 18. Comparison of normalized ventilation rate of the second-floor central unit with wing walls installed on all nine units.

In summary, the experimental results showed that, in the cases without wing walls, stronger pressure and velocity fluctuations were present near the windward side of the building, while these fluctuations gradually weakened toward the leeward locations. As a result, the normalized ventilation rate was generally highest at 0° wind direction, except for the second-floor leeward-side unit. Between the 45° and 90° cases, the 90° wind direction consistently produced higher ventilation rates than 45°. This may be attributed to the stronger instantaneous pressure difference, turbulent fluctuations, and larger projected opening area when the wind approached normal to the façade.

In contrast, when wing walls were installed, the ventilation performance varied depending on the unit location and wind direction. A decrease in ventilation rate was observed for the windward-side units under the 0° wind direction, suggesting that the wing walls may have interfered with the airflow when the wind was parallel to the façade. However, the ventilation rate increased for the central and leeward-side units. Overall, the wing walls were most effective at 45°, where the oblique wind direction likely produced stronger localized pressure differences and enhanced airflow redirection toward the openings.

Therefore, the results indicate that the effectiveness of wing walls is strongly dependent on both wind direction and unit location, with the greatest improvement occurring under oblique wind conditions.

Computational Fluid Dynamics (CFD) Simulation

This research utilized OpenFOAM software in analyzing conservation equations for mass and momentum through finite volume method. To ensure better consistency between experimental and numerical results, the boundary conditions in the simulations were set to match those used in the experiments, particularly for the wind tunnel test section, as shown in the figure below. The upstream and downstream domain extents were defined following the Best Practice Guidelines for CFD Simulation of Flows in the Urban Environment (Franke & Baklanov, 2007).

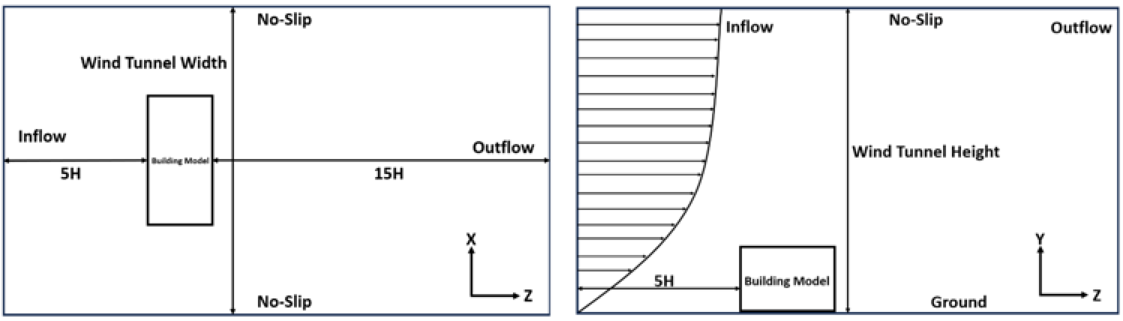


Figure 19. Computational domain and boundary conditions for the CFD simulation.

Preliminary CFD Results

Preliminary CFD simulations were conducted for the 3×3 building model using the Reynolds-Averaged Navier-Stokes (RANS) approach with a steady-state solver and the k-ω SST turbulence model. The simulations compared the velocity contours and air change rate across two floors (second and third) to assess the ventilation effectiveness in each unit with and without the installation of wing walls.

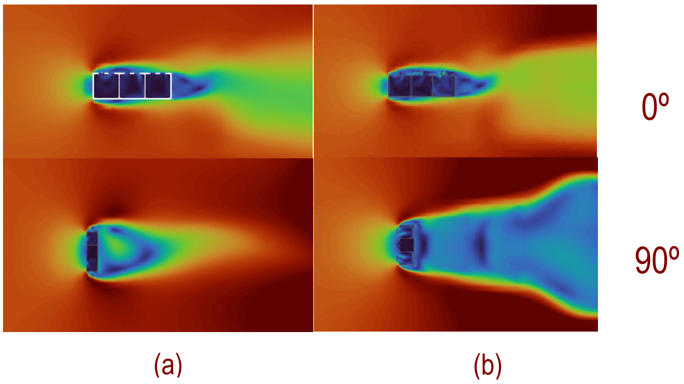


Figure 20. Velocity distribution at the second-floor of the 3x3 building without (a) and with (b) wingwall.

The figure above illustrates the velocity distribution at the second-floor level of the building for the cases with and without wing walls. Correspondingly, Figures 21 and 22 presents the Air Change per Hour (ACH) values of the selected testing units in the 3x3 apartment building model. The results indicate that the effect of the wing wall depends on both the wind direction and the location of the unit within the building. For the windward units under a 0° wind direction, the installation of the wing wall led to a reduction in ventilation performance. In contrast, under a 90° wind direction, the presence of the wing wall increased ventilation in the windward units. Meanwhile, the center and leeward-side units generally exhibited improved ventilation with wing walls at both 0° and 90° wind directions.

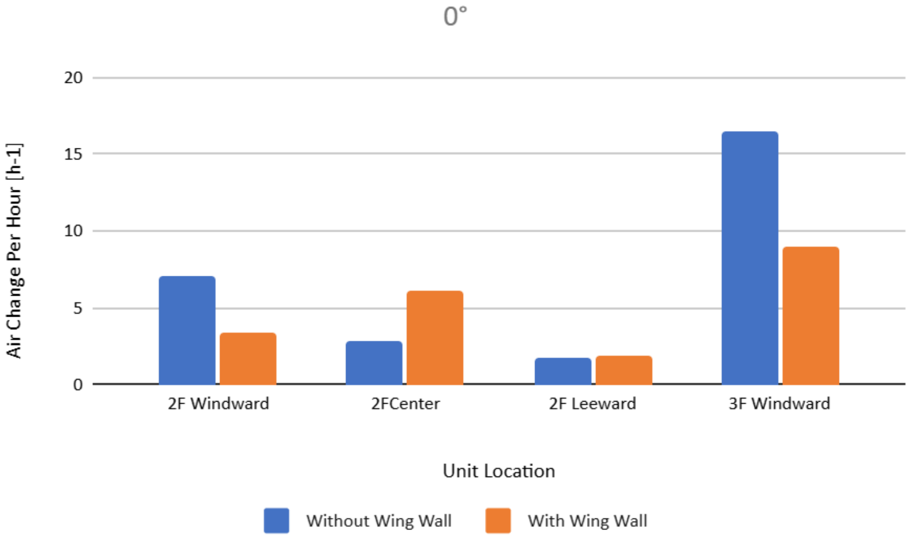


Figure 21. Air Change per Hour of 3x3 Building without wing wall at 0° Wind Direction.

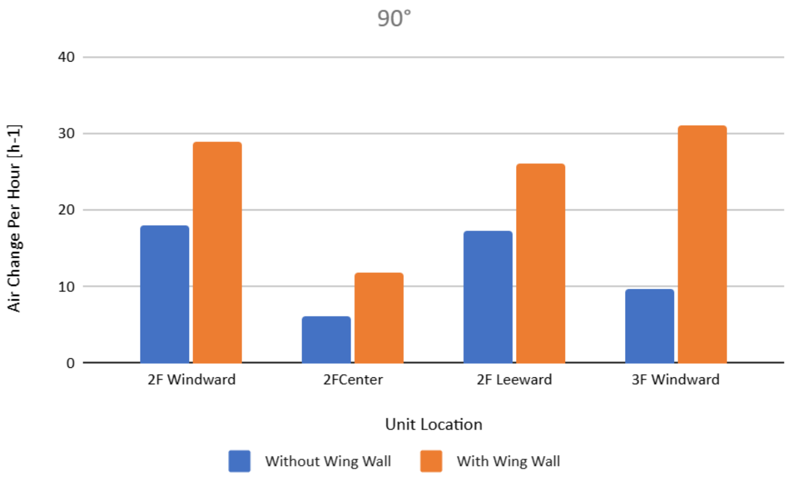


Figure 22. Air Change per Hour of 3x3 Building without wing wall at 90° Wind Direction.

These results suggest that wing walls modify the local airflow pattern around the façade, thereby altering the wind capture and distribution of air entering the openings. In the windward units, the benefit of the wing wall was not uniform, since its effect depended on the alignment of the incoming wind relative to the façade and opening. Under 0° wind direction, the wing wall may have partially obstructed or redirected the approaching flow away from the windward opening, resulting in lower ventilation. However, at 90° wind direction, the same element likely enhanced the deflection of airflow into the opening, leading to higher ACH. For the center and leeward-side units, the improvement observed in both wind directions indicates that the wing wall helped redistribute airflow more effectively along the building façade, promoting better cross-facade interaction and increased air entry into these less directly exposed spaces.

Overall, the findings indicate that the addition of wing walls can improve wind-driven ventilation performance, but the magnitude and direction of the effect vary according to wind orientation and unit position. The results further imply that wing walls are more beneficial in areas where airflow needs to be redirected or concentrated toward the openings, rather than in locations where the incoming wind is already directly incident on the façade.

CFD Results

To further evaluate the airflow behavior at different elevations, CFD results were analyzed in terms of the velocity distribution across the first, second, and third floor levels under varying wind directions. This was done to determine how the approaching flow interacts with the building façade and how the resulting air speed differs with height. Through this analysis, the influence of elevation on local airflow conditions and ventilation potential can be more clearly assessed.

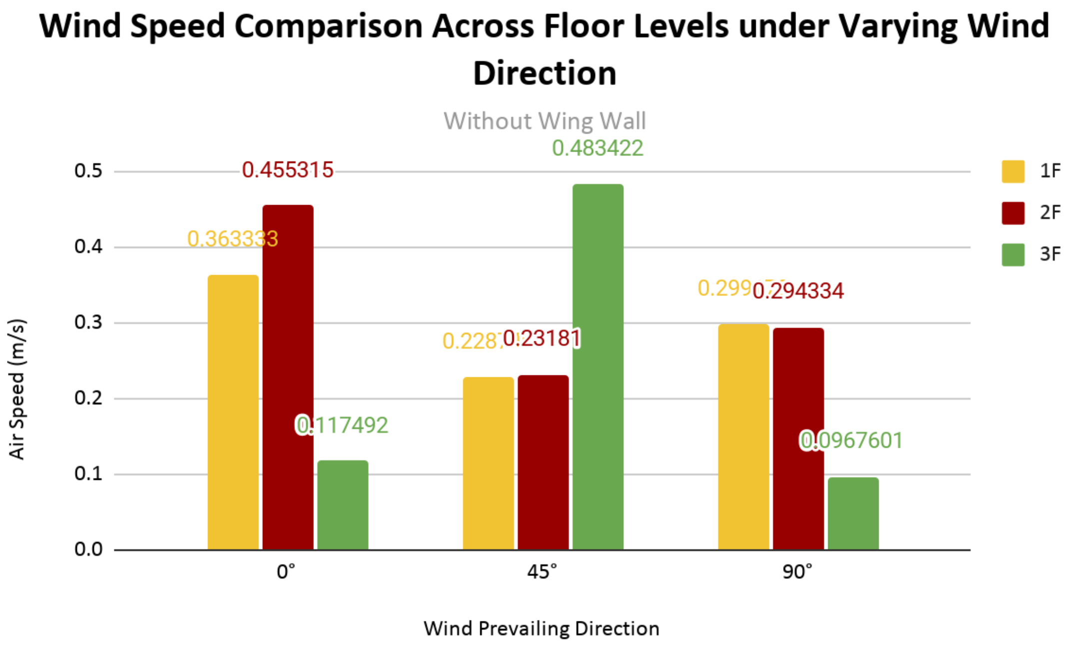


Figure 23. Wind Speed Across Floor Levels Without Wingwall.

Figure 23 shows that, in the absence of wing walls, the airflow distribution varied considerably across floor levels depending on wind direction. Under a 0° wind direction, the second floor exhibited the highest air speed, followed by the first floor, while the third floor recorded the lowest value. This indicates that the lower floors were more favorably positioned to capture the approaching flow under normal wind incidence. At 45°, however, the third floor showed a substantial increase and became the most ventilated level, suggesting that the oblique wind direction created a more favorable airflow path toward the upper opening. In contrast, the first and second floors received comparatively lower airflow under this condition. At 90°, the first and second floors again showed higher and nearly equal air speeds, while the third floor remained the least ventilated. Overall, these results indicate that, without wing walls, the natural wind-driven ventilation performance is strongly dependent on floor level and wind direction, with certain orientations favoring lower-floor openings and others promoting airflow toward the upper level.

Conclusion

Therefore, the combined experimental and CFD findings suggest that wing walls can improve natural ventilation performance, but their effectiveness is highly dependent on wind orientation and unit location. The wing walls were most beneficial under the 45° wind direction, where the oblique airflow could be redirected and concentrated toward the openings, resulting in higher ventilation rates particularly for the central and leeward-side units. Improvements were also observed at 90°, where the airflow approached the façade more directly and the wing walls helped guide air into the openings.

However, under the 0° wind direction, the airflow was parallel to the building façade and window opening but perpendicular to the wing wall surface. In this case, the wing wall may have acted as a local obstruction to the approaching flow, causing stagnation, flow separation, or deflection away from the window. This explains why the windward-side units showed lower ventilation rates with wing walls at 0°. Overall, the findings suggest that wing walls can improve wind-driven ventilation when the incoming airflow is favorably oriented toward the façade and opening. However, their effectiveness is not uniform across all cases, as ventilation performance is influenced by the combined effects of wind direction, façade orientation, unit location, and wing wall placement.

4. Published Paper etc.

[Underline the representative researcher and collaborate researchers]
[Published papers]
1.
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[Presentations at academic societies]
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[Published books]
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[Other]
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5. Research Group

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6. Abstract (half page)

Research Theme:
Creating an Eco-Friendly Wing Wall to Enhance Sustainability, Energy Efficiency, and Livability in the Well-Designed High-Rise Office and Residential Buildings

Representative Researcher (Affiliation):
Napoleon A. Enteria, PhD (Mindanao State University – Iligan Institute of Technology)

Summary・Figures:

This study investigated the effect of wing walls on wind-driven ventilation in a multi-unit, multi-storey apartment building using tracer-gas experiments and computational fluid dynamics (CFD). A 3×3 apartment building model was tested under three wind directions: 0°, where airflow was parallel to the façade and window opening; 45°, representing oblique wind incidence; and 90°, representing airflow normal to the façade. Preliminary tracer-gas testing confirmed the suitability of dimensionless concentration and normalized ventilation rate as performance indicators. Final experiments were conducted at an approximately constant reference wind speed of 5 m/s and a fixed gas emission rate of 420 cc/min, focusing on selected windward, central, and leeward units.

Results showed that ventilation performance varied with wind direction, unit location, and wing wall installation. Without wing walls, airflow effects were generally stronger near windward locations and weaker toward leeward units. With wing walls, the normalized ventilation rate increased notably in the central and leeward-side units, especially at 45°, indicating that oblique airflow improved the ability of wing walls to redirect air toward the openings. However, ventilation decreased in windward-side units at 0°, where the airflow was parallel to the façade but perpendicular to the wing wall surface, causing possible stagnation, separation, or deflection away from the window. CFD results further showed that air speed distribution varied across floor levels and wind directions. Overall, the findings suggest that wing walls can enhance wind-driven ventilation when properly oriented with prevailing winds, highlighting their potential as a passive architectural strategy for improving natural ventilation, reducing reliance on mechanical cooling, and supporting energy-efficient building design in dense urban settings.