Wind Engineering Joint Usage/Research Center
FY2024 Research Result Report

Research Field: Outdoor Environment
Research Year: FY2024
Research Number:
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: Napoleon A. Enteria, PhD

Budget [FY2024]: 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.

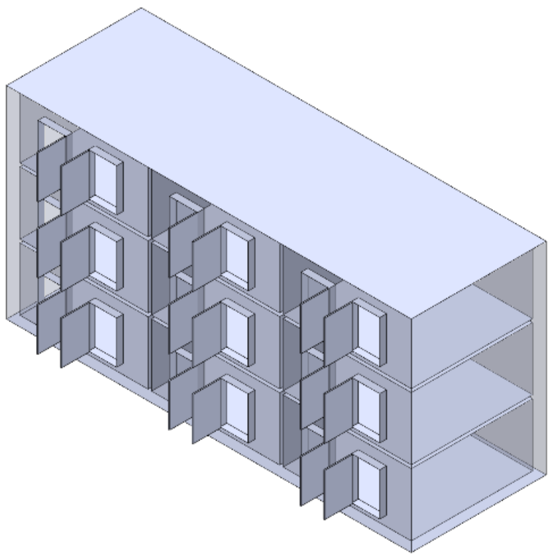

Figure 1. Multi-unit multi-storey building with wing walls.

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).

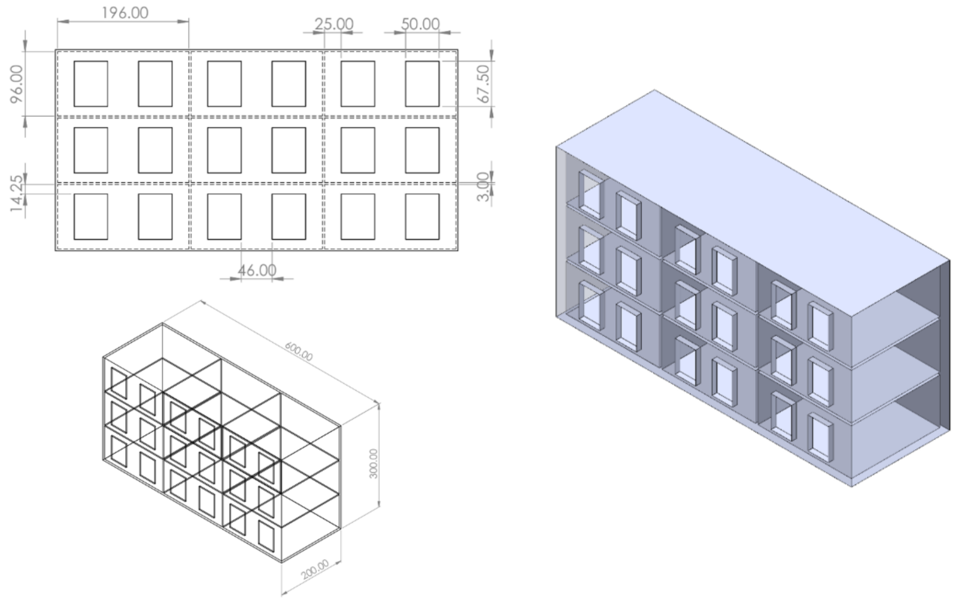

Figure 2. Modeled 3x3 single-sided ventilated building.

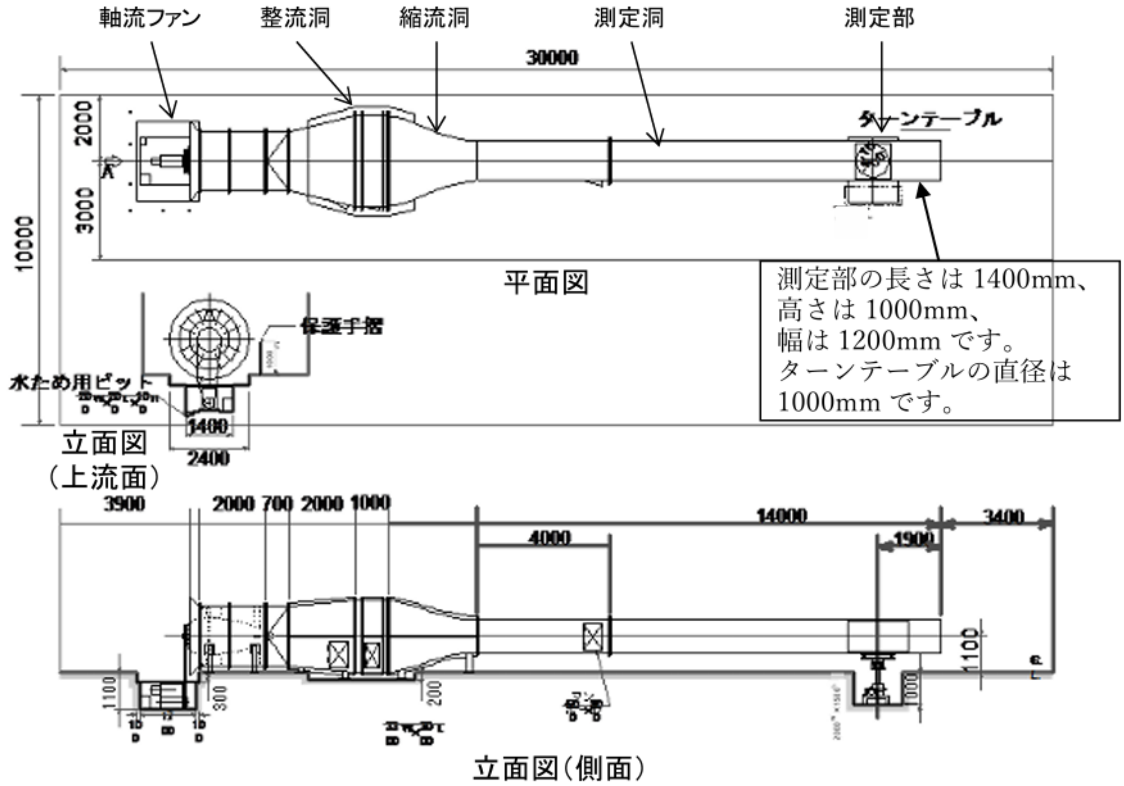

Figure 3. Wind tunnel plan and elevation view.

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.

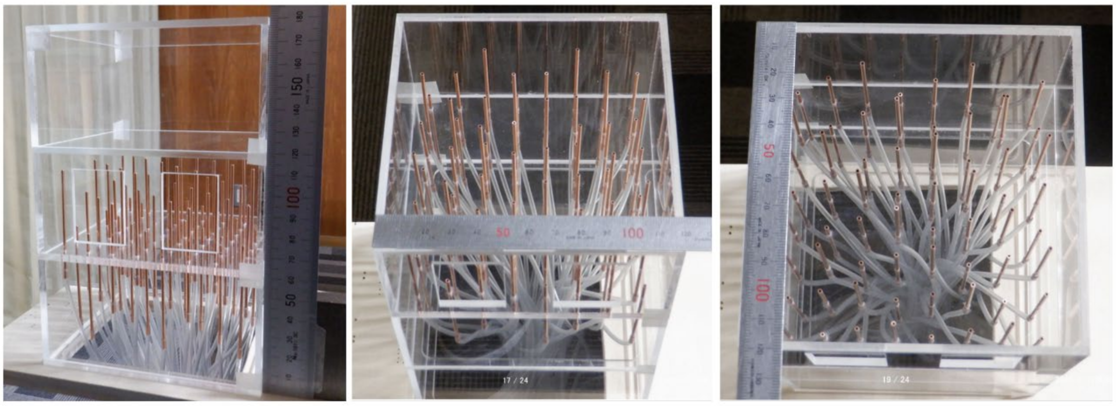

Figure 4. Fabricated 3x3 building model.

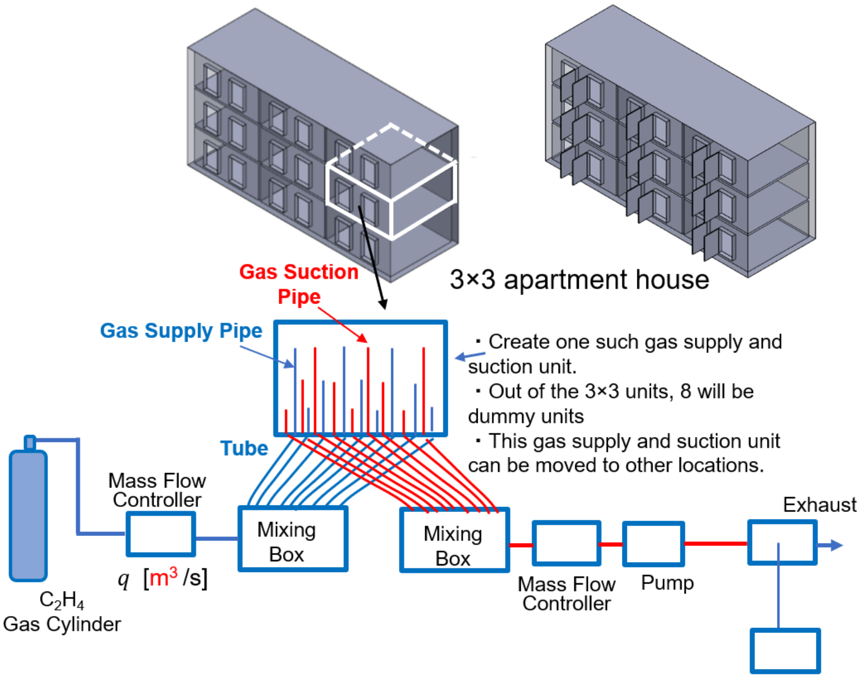

Figure 5. Setup for tracer gas method.

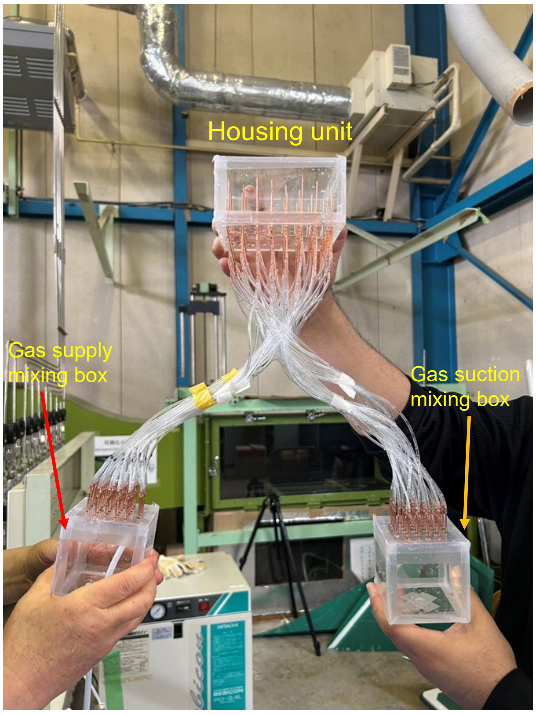

Figure 6. Fabricated building model equipped with gas supply and suction mixing boxes for tracer gas dispersion and sampling.

Figure 7. Gas supply station and mass flow controller.

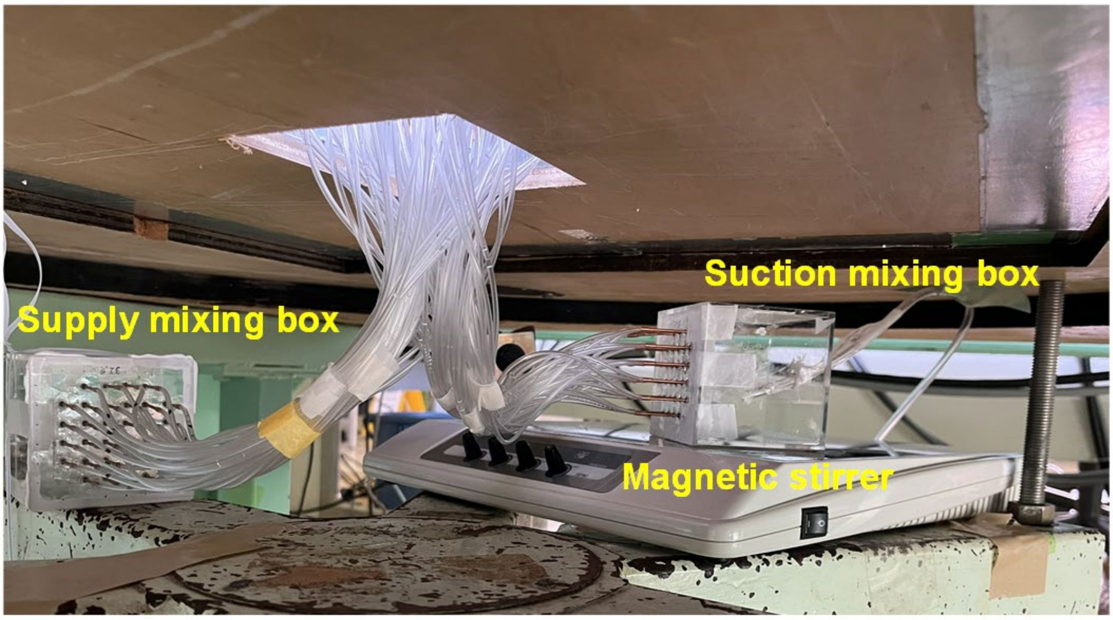

Figure 8. Installation status of the mixing box under the wind tunnel floor.

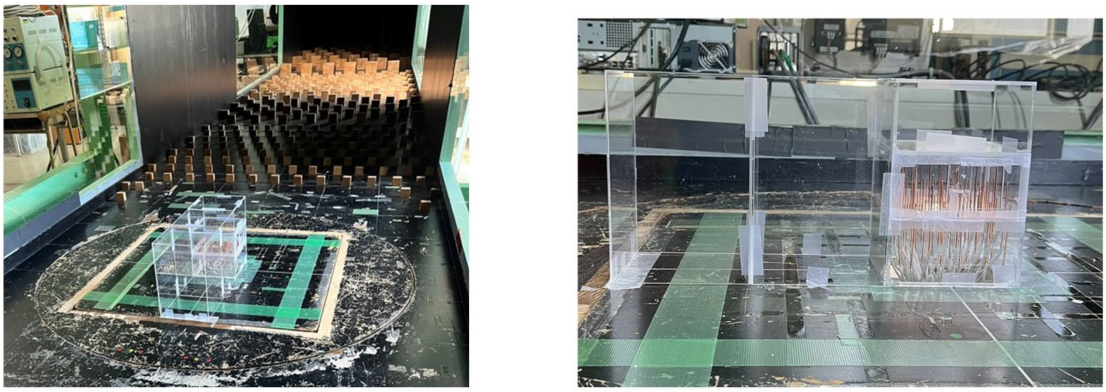

Figure 9. Model installation status in the wind tunnel.

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.

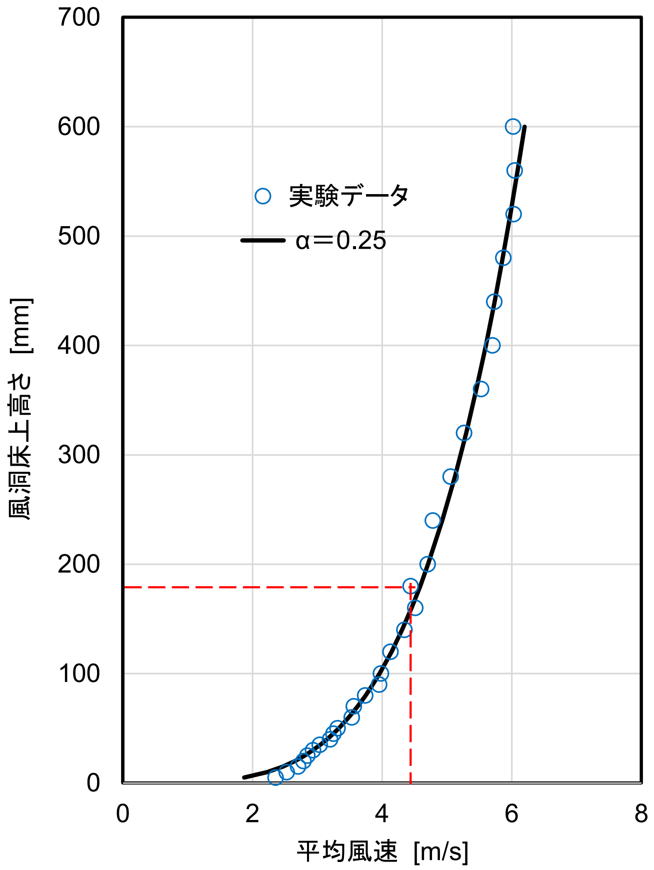

Figure 10. Wind velocity profile.

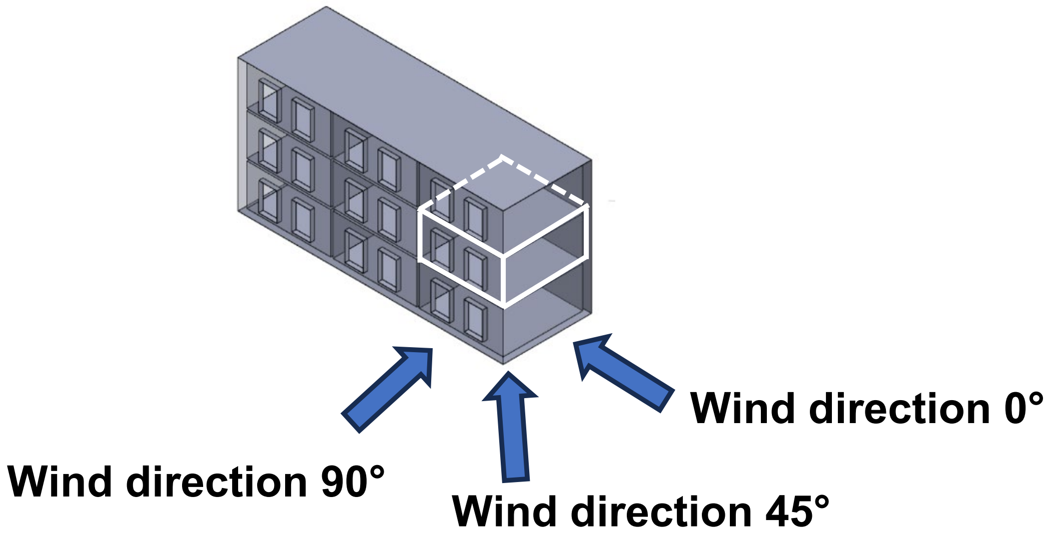

Figure 11. Schematic of wind directions approaching the 3x3 building model for ventilation testing.

Consequently, table 1 summarizes the ventilation performance results under each wind direction.

Table 1. Tracer Gas experimental result.

Wind Direction [θ]	Reference Wind Speed [U_H]	Gas Flow [q]		Average Concentration [C]	Effective Ventilation Rate [Q_E]	Window Opening Area [A]	Normalized Ventilation Rate [K]	Room Volume [V]	Average Air Age [t]	Effective Ventilation Rate [n]
[°]	[m/s]	[cc/min]	[m^3/s]	[m^3/m^3]	[m^3/s]	[m^2]	[-]	[m^3]	[s]	[1/s]
0	4.59	250	4.17E-06	3.90E-05	0.1068	0.0022	10.39	0.0007	0.007	152.24
45	4.59	250	4.17E-06	1.49E-03	0.0028	0.0022	0.27	0.0007	0.251	3.98
90	4.59	250	4.17E-06	1.28E-03	0.0033	0.0022	0.32	0.0007	0.216	4.63

The three wind directions (0°, 45°, and 90°) were analyzed under a constant reference wind speed of 4.59 m/s. The gas emission rate was fixed at 250 cc/min, corresponding to 4.17×10^{-6} m^3/s across all cases. Results showed that the average tracer gas concentration was lowest at 0° (3.90×10^{-5} m^3/m^3), while significantly higher concentrations were observed at 45° (1.49×10^{-3} m^3/m^3) and 90° (1.28×10^{-3} m^3/m^3), indicating reduced ventilation efficiency with oblique wind incidence. The effective ventilation rate (QE) was highest at 0° (0.1068 m^3/s), while much lower values were recorded at 45° (0.0028 m^3/s) and 90° (0.0033 m^3/s). The window opening area remained constant at 0.0022 m^2 throughout the tests. Normalized ventilation rates (K) further confirmed these trends, with a high value at 0° (10.39) and much lower values at 45° (0.27) and 90° (0.32). The room volume was small and constant at 0.0007 m^3. Additionally, the average air residence time was shortest at 0° (0.007 seconds), indicating rapid air exchange, and longer at 45° (0.251 seconds) and 90° (0.216 seconds), implying slower ventilation. Finally, the effective air exchange rate (n) was extremely high at 0° (152.24 1/s) and decreased significantly to 3.98 1/s at 45° and 4.63 1/s at 90°, highlighting the strong influence of wind direction on natural ventilation performance.

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 inflow, as shown in the figure below.

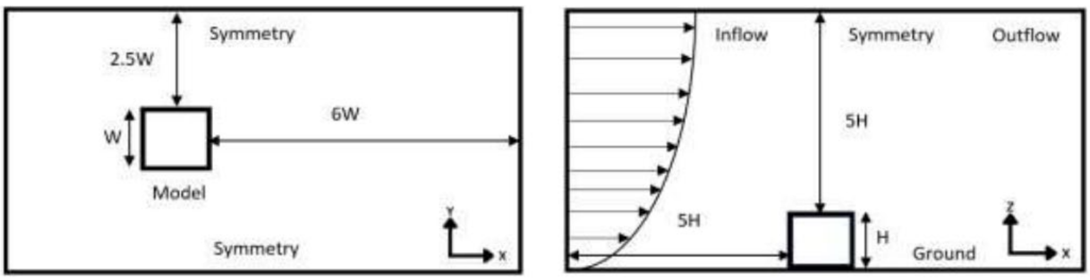

Figure 12. Computational domain and boundary conditions for the simulation, showing inflow, outflow, ground, and symmetry planes relative to the building model.

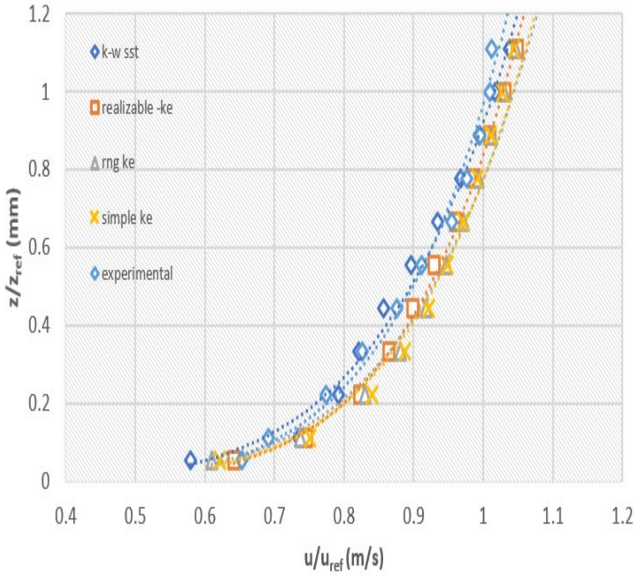

Figure 13. CFD and Wind Tunnel comparison.

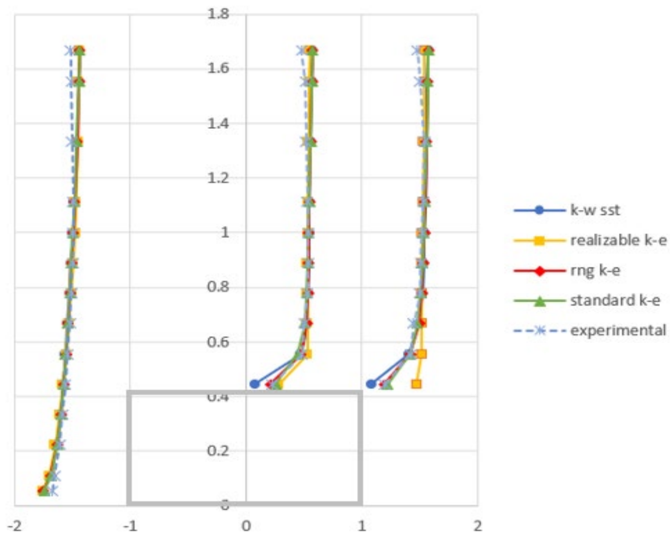

Figure 14. Turbulence Modeling Validation

Figures 13 and 14 present validation results comparing CFD simulations with experimental wind tunnel data. It includes results obtained using various turbulence models: k-ω SST, realizable k-ε, RNG k-ε, standard k-ε, and simple k-ε. The close alignment between CFD and experimental results confirms that the turbulence models, particularly the k-ω SST model adequately capture the boundary-layer velocity profiles in regions upstream and the roof area where the flow separation is commonly involved.

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 velocity contours across three floors (first, second, and third) under two configurations: without wing walls and with wing walls.

Across all floors, the presence of wing walls generally led to improved airflow distribution around the building façade. On the first and second floors, the velocity magnitude near the openings was higher with wing walls, suggesting enhanced wind capture and improved ventilation potential. In contrast, simulations without wing walls exhibited lower airflow velocities around the openings, indicating weaker ventilation performance. On the third floor, however, the impact of the wing wall appeared less pronounced, with relatively small differences in the flow fields between the two cases.

Overall, the preliminary results suggest that the addition of wing walls can enhance wind-driven ventilation, particularly on the lower floors, by increasing the airflow interaction at the building facade.

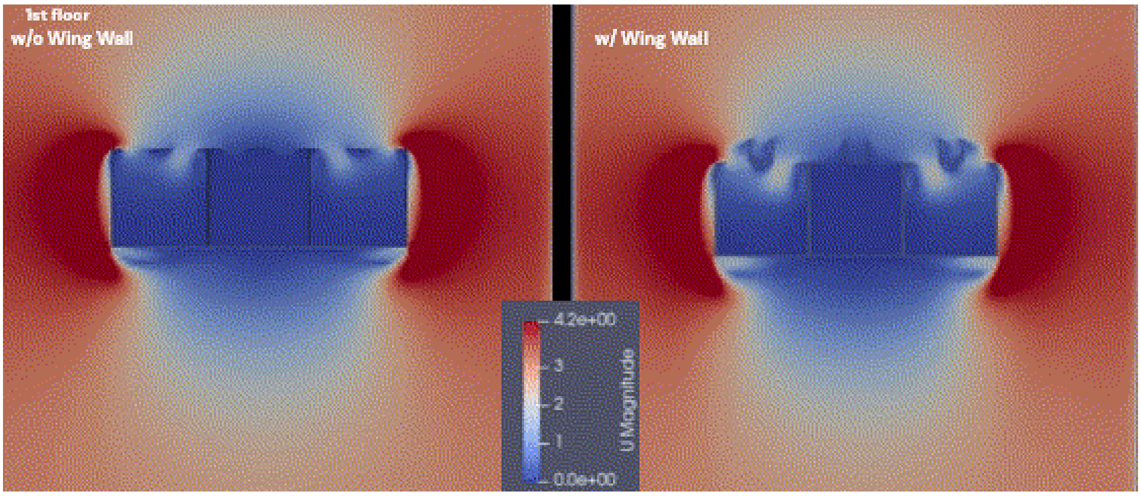

Figure 15. Velocity distribution at the first floor without wing wall (left) and with wing wall (right).

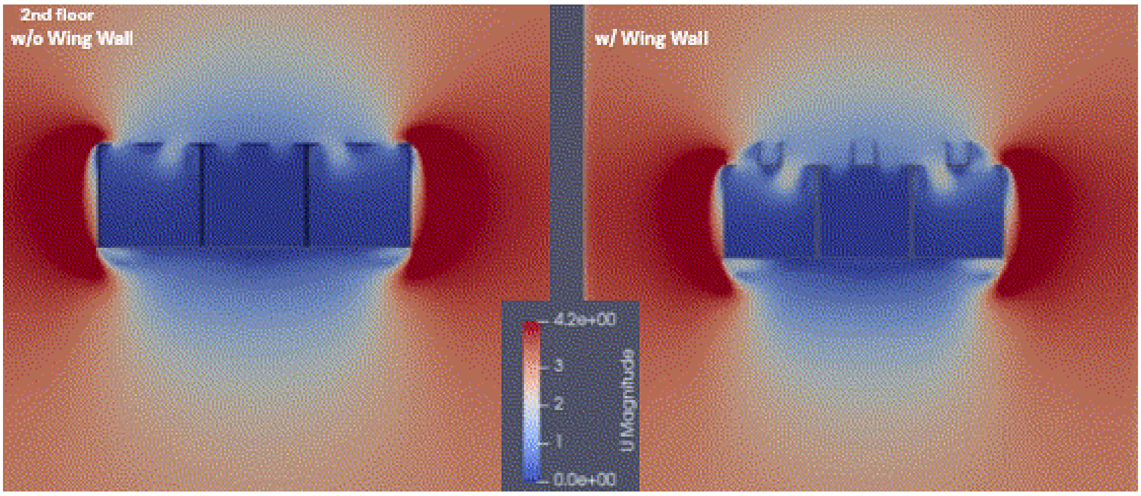

Figure 16. Velocity distribution at the second floor without wing wall (left) and with wing wall (right).

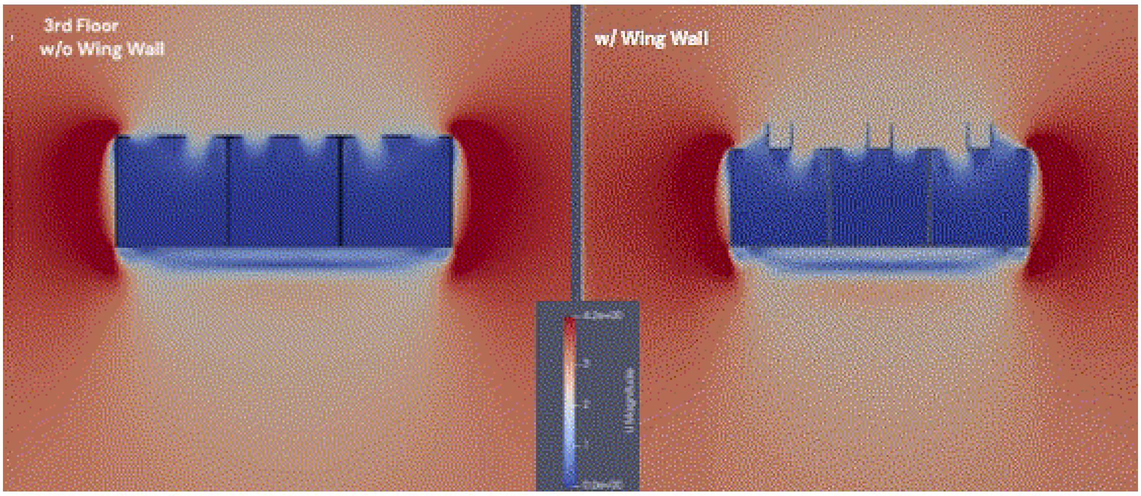

Figure 17. Velocity distribution at the third floor without wing wall (left) and with wing wall (right).

4. Published Paper etc.

[Underline the representative researcher and collaborate researchers]

[Published papers]

1.

2.

[Presentations at academic societies]

1.

2.

[Published books]

1.

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[Other]

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5. Research Group

1. Representative Researcher

Napoleon A. Enteria, Professor, Mindanao State University – Iligan Institute of Technology

2. Collaborate Researchers

1. Ryuichiro Yoshie, Professor, Tokyo Polytechnic University
2. Kanako Endo, Tokyo Polytechnic University
3. Koshin Iio, Tokyo Polytechnic University
4. Jean Kate Hansel C. Simprota, Mindanao State University – Iligan Institute of Technology
5. James Marty T. Cardiño, Mindanao State University – Iligan Institute of Technology

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 explores the impact of integrating eco-friendly wing walls on natural ventilation and energy efficiency in high-rise office and residential buildings. Using a combination of wind tunnel experiments and CFD simulations, a three-storey, multi-unit building model was tested under varying wind directions (0°, 45°, 90°) and a fixed wind speed. The tracer gas method, employing ethylene (C_2H_4), measured the ventilation effectiveness by analyzing tracer gas concentration, effective ventilation rates, and air exchange rates. Results indicated significant improvements in natural ventilation performance at direct wind incidence (0°), with notably lower ventilation effectiveness observed at oblique angles (45°, 90°). Preliminary CFD analysis further validated that wing walls effectively enhanced airflow distribution, particularly on lower floors. This research highlights the potential of wing walls in improving sustainable architectural design through better ventilation and reduced energy consumption in urban high-rise settings.