A Study on the effect of the Wind Catcher in Apartment Buildings

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Abstract. In recent years, there has been growing emphasis on natural ventilation for energy conservation and intellectual productivity. However, in urban areas with a high building density, it is difficult to let in fresh outdoor air into the room, and installing a wind catcher (WC) is considered an effective solution. In this study, we conducted wind tunnel experiments and computational fluid dynamics (CFD) analysis to verify the ventilation-enhancing effects of installing WC in apartment buildings. Two models are used in this study. In the initial stages of wind tunnel testing and CFD analysis, we used a model without adjoining rooms to determine the correspondence of the wind tunnel test values to the CFD analysis values. Subsequently, CFD analysis was performed using the model with an adjacent room, and comparisons were made with the model without an adjacent room. Using the model with an adjacent room, we also studied the difference in the ventilation volume depending on the wind direction and ventilation volume with a single-sided opening. Consequently, we determined the following:

1. The pressure difference between the inlet and outlet openings was smaller in the model with an adjacent room than in the model without an adjacent room, and the ventilation volume was smaller. In other words, installing a WC in an apartment building can create a pressure difference, which is considered effective in promoting ventilation.
2. The WC works effectively for the wind flowing parallel to the opening.

Keywords. CFD analysis, natural ventilation, wind catcher, wind tunnel experiment
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1. Introduction

To improve the thermal and air environment in houses, it is important not only to use air conditioning equipment but also to let in fresh outdoor air to save energy and improve intellectual productivity. In addition, with the recent outbreak of COVID-19, letting in fresh outdoor air into rooms as a measure to prevent infection has become an issue. However, in urban areas, where buildings are densely constructed, it is often difficult to obtain sufficient ventilation through wall-to-wall openings. To address this issue, previous studies have shown the effect of wind catcher (WC) in promoting ventilation, and it is expected that an increasing number of buildings will attempt to do so in the future (Fig. 1). [1]

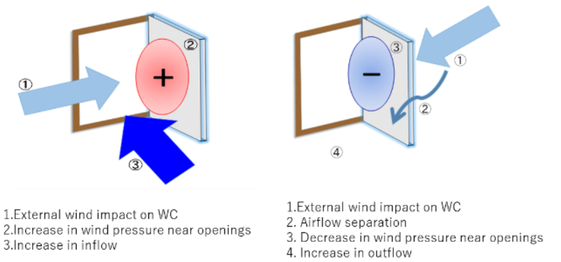

Fig. 1 – Working mechanism of WC

The purpose of this study was to confirm the effect of WCs through wind tunnel experiments and numerical simulation of flow (hereinafter referred to as computational fluid dynamics (CFD) analysis), to confirm the performance of each WC installation pattern by CFD analysis, and to understand the factors influencing ventilation performance.

2. Method

2.1 wind tunnel experiment

The experiment was conducted using an Eiffel-type wind tunnel at Tokyo Polytechnic University. The experimental model was a room in an apartment complex, and the adjacent dwelling was omitted (Fig. 2). The model eave height was set as the reference height (Z_0 = 226.6 mm), eave height wind velocity of the approaching flow (V_0 =7 m/s) was set as the reference velocity, and dynamic pressure based on the reference velocity was set as the reference pressure P0. The wall and room pressures near each opening were measured from the pressure measurement points placed on the model (Fig. 3), and the ventilation volume Q was calculated using Equation (1). Q[m^3/s] denotes the ventilation volume, α [-] is the flow coefficient, A[m^2] is the opening area, ρ[kg/m^3] is the air density, and ΔP[Pa] is the pressure difference.The calculation assumes that α is 0.6, which is the value for a typical opening. The approaching flow is the profile according to the 1/4 power law assuming an urban area, the study cases are the six cases shown in Fig. 4, and the wind direction is the direction of the arrow in Fig. 4.

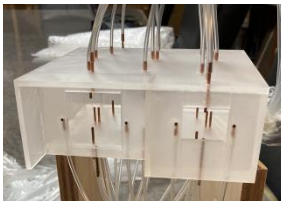

Fig. 2 - Wind Tunnel Experiments model

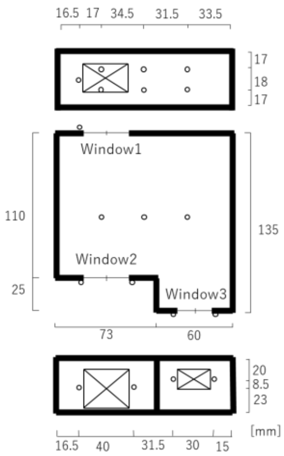

Fig. 3 - Pressure measurement point of the model

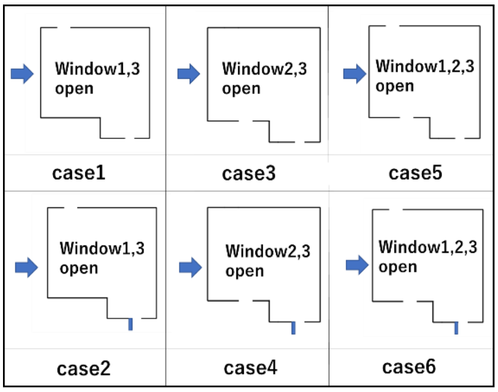

Fig. 4 – Study case

$$Q = \alpha A \sqrt{\frac{2}{\rho}\Delta P} \quad (1)$$

The measurement results for the mainstream and spanwise components of the approaching flow are shown in Fig. 5. The measured values of the former generally agreed with the distribution of the 1/4 power law at each height, whereas the measured values of the latter were generally 0 m/s.

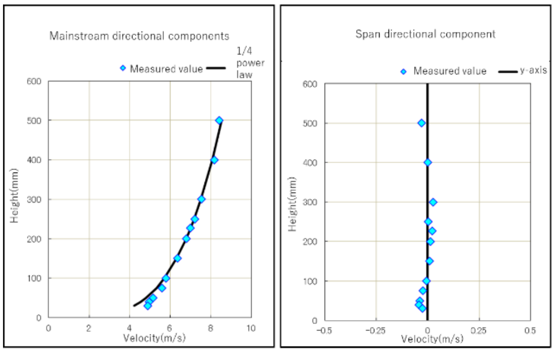

Fig. 5 - Approach flow measurement results

2.2 CFD analysis

An analytical model was constructed to simulate an experimental wind tunnel model. The turbulence model was a standard k–ε model, and the inflow condition was the approaching flow measured in the wind tunnel experiment (Tab. 1 and, Fig. 6).

Tab. 1 - CFD boundary conditions

boundary	Boundary conditions
Inlet surface	Profile based on 1/4 power law $U = U_0(Z/Z_0)^{0.25}$ Standard wind speed (U_0 = 1.0m/s) Eave height (Z_0 = 1.0m)

Outlet surface	Free flow
Top and sides	Free slip
ground	Wall function based on the general logarithmic law

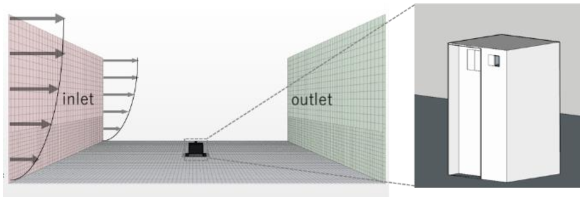

Fig. 6 – CFD analysis model

3. Validation

Fig. 7 shows a comparison between the ventilation rate obtained from the pressure measurements in the wind tunnel experiment and the CFD analysis. The standardized ventilation volume is the product of the wind speed at each eave height and the square of the eave height. From the results, it is observed that there are some differences between the wind tunnel experimental values and the CFD analysis, although the trend of the ventilation volume conversion was consistent. In the CFD analysis, the wind pressure at the apertures was measured using a shield model with the apertures blocked, and the flow coefficient α for each aperture was calculated as $\alpha1 = 0.39$, $\alpha2 = 0.41$, and $\alpha3 = 0.52$. In the wind tunnel experiment, the flow coefficient α was fixed at 0.6 and the ventilation volume conversion calculated from the wind pressure may have been overestimated. Fig. 7 also shows that the ventilation volume decreased when the WC was installed in the full opening pattern. It is expected that the installation position of the WC in the case under consideration will obstruct ventilation in the opposite direction.

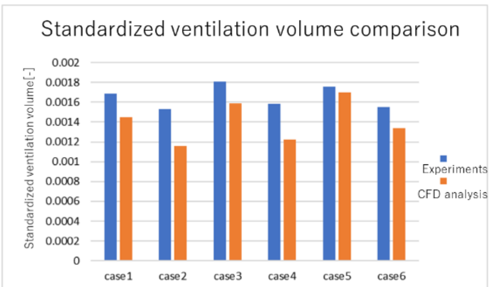

Fig. 7 - Standardized ventilation volume comparison

4. Additional study

4.1 Outline

Because the ventilation enhancement effect of the WC installation was not obtained in the wind tunnel experiment, an additional study was conducted using CFD. Based on the pressure distribution in the wind tunnel experiment, it was expected that window 3 was the inflow opening and windows 1 and 2 were the outflow openings. Therefore, based on case 1, the WC was installed at a position that increased the pressure at window 3 and decreased the pressure at window 1 (Fig. 8), and the wind direction angle was determined by the wind tunnel experiment. The wind direction angle was the same as that used in the wind tunnel experiment.

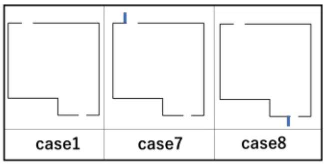

Fig. 8 - Study case

4.2 Result

Figure 9 shows the results of the ventilation volume comparison. Cases 1 and 7 show a decrease in ventilation volume, indicating that the WC installed on the windward side of window 1 had no effect on ventilation. The results of the comparison between cases 1 and 7 show that the amount of ventilation decreased, and the WC installed on the windward side of window 1 had no effect on ventilation.

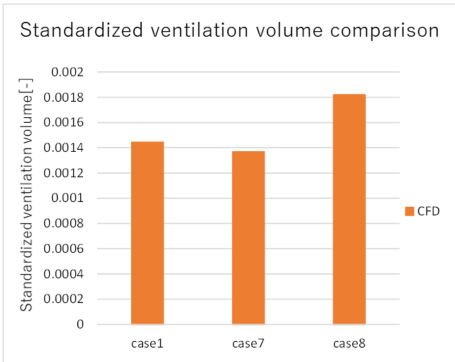

Fig. 9 - Standardized ventilation volume comparison

4.3 Discussion

The pressure contour diagram is shown in Fig. 10. From this, it can be confirmed that in case 8, the wind collided with the WC installed on the leeward side of window 3, the pressure near the opening increased, and the pressure near window 1 was significantly negative. Consequently, the pressure difference between the inflow and outflow openings increased, leading to an increase in the ventilation volume. Next, in case 7, by installing the WC on the upwind side of window 1, the peeling pressure of the airflow is blocked and the negative pressure at the outflow opening cannot be built up. This reduced the pressure difference between the inflow and outflow apertures, leading to a decrease in the ventilation volume.

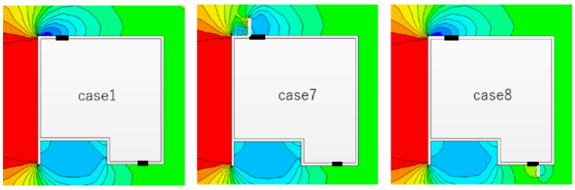

Fig. 10 - Pressure contour diagram

5. Study in a model with adjacent rooms

5.1 Outline

The CFD analysis was performed using a model with an adjacent room on the upwind side of the target room (Fig. 11), which could not be performed in the wind tunnel experiment. The items to be studied were the comparison of ventilation volume by different WC installation patterns and the comparison of ventilation volume by wind direction in the model with adjacent rooms.

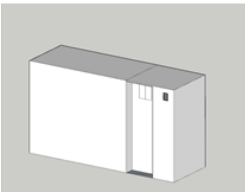
Fig. 11 - Model with adjacent rooms

5.2 Result for different WC installation patterns

The four studied cases are shown in Fig. 12. The ventilation volume comparison results for each case are shown in Fig. 13. In the model with an adjacent room upwind, the ventilation rate was significantly lower in the case with no WC (case 9). Next, looking at the standardized ventilation volumes for cases with WC upwind of window 1 (case 10) and downwind of window 3 (case 11), the values increased significantly in both cases. The largest value was obtained when the WC was installed both upwind of window 1 and downwind of window 3 (case 12).

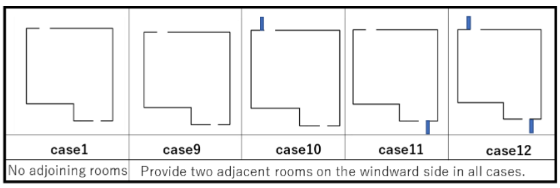

Fig. 12 - Study case

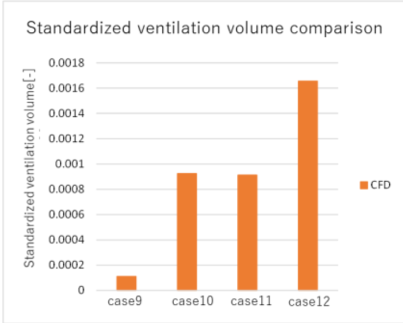

Fig. 13 - Standardized ventilation volume comparison

5.3 Discussion

The pressure contour diagram is shown in Fig. 14. The pressure contour diagram for case 9 shows that there is almost no pressure difference between the inlet and outlet openings. Referring to the pressure contour diagram of cases 10 and 11, we observe that the pressure difference is caused by the installation of the WC. It is observed that when the WC is installed on both the windward side of window 1 and leeward side of window 3 (case 12), the pressure difference between the inlet and outlet openings is the largest, and the ventilation rate is the highest. This indicates that the installation of a WC in a single building, which is susceptible to airflow separation, may decrease the ventilation volume; however, in a long building such as an apartment building, it is easy to obtain the ventilation promotion effect by installing a WC.

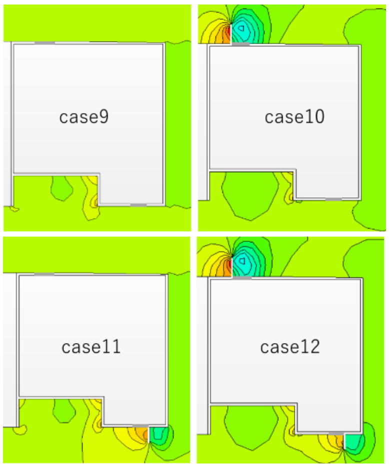

Fig. 14 - Pressure contour diagram

5.4 Result for different wind directions

We compare the ventilation rate by wind direction using a model with adjacent rooms. The study cases are cases 9 and 11 shown in Fig. 12. The wind direction is shown in Fig. 15. The results of the ventilation rate comparison are shown in Fig. 16, and the wind-speed vector diagrams for each case are shown in Fig. 17. From these figures, the ventilation rate is highest when the wind direction angle was 0°. When the wind direction angle was 0°, the ventilation enhancement effect of the WC could not be confirmed. In contrast, when the wind direction angles are 90° and 270°, the ventilation rate is remarkably low in the case without a WC, but in the case with a WC, there is an improvement in the ventilation rate.

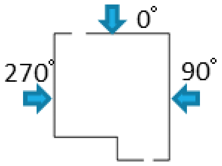

Fig. 15 - Wind direction angle

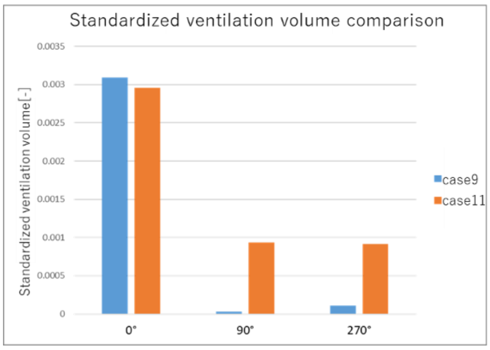

Fig. 16 - Standardized ventilation volume comparison

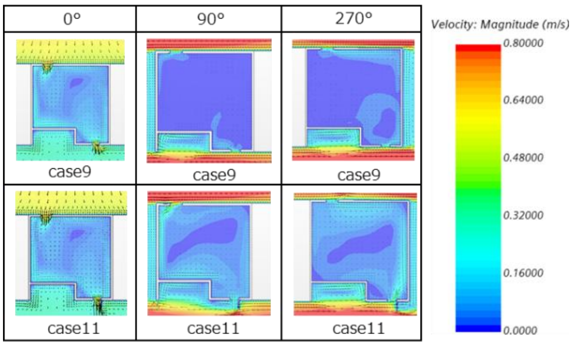

Fig. 17 - Wind velocity vector diagram

6. Conclusion

1. The pressure difference between the inlet and outlet openings was smaller in the model with an adjacent room than in the model without an adjacent room, and the ventilation volume was smaller. In other words, installing a WC in an apartment building can create a pressure difference, which is considered effective in promoting ventilation.

2. A WC works effectively for wind flowing parallel to the opening

7. References

[1] Oda T et al. Effects of Wind Cather on Improvement in Cross-Ventilation Performance, Roomvent 2014

c. The datasets generated during and/or analysed during the current study are not available because it is currently in preparation, but the authors will make every reasonable effort to publish them in near future.