Study on the improvement of ventilation performance using a wind catcher

Mitsuru Takuwa 1, Takashi Kurabuchi 1, Jeongil Kim 1, and Koichiro Saito 2

1 Department of Architecture, Faculty of Engineering, Tokyo University of Science, Tokyo, Japan
2 YKK AP Inc., Tokyo, Japan

Abstract. Global warming countermeasures are needed worldwide, and Japan has set a goal of achieving carbon neutrality by 2050. In addition to the use of natural energy sources, energy-saving technologies are being considered to achieve this goal. In this study, computational fluid dynamics (CFD) analysis and field measurements were conducted to determine the increase in the ventilation rate using wind catchers (WCs), which can be employed to increase the ventilation rate without CO₂ emissions. The study was conducted in a pair of symmetrical dwelling units, one of which had a pair of WCs on the south wall and the other had a double sliding window on the south wall. Field measurements and CFD analyses were performed for four cases determined using a combination of openings in the subject dwelling unit. The cause was confirmed from the analysis results based on the pressure change at the opening and wind flow, and the difference between the dwelling units with and without a WC was analyzed. We found that installing a WC in a single-sided opening improves the ventilation performance. Furthermore, the WC may prevent the original inflow and outflow depending on the wind direction angle.

1. Introduction

The Global Warming Prevention Plan was revised to achieve carbon neutrality by 2050. The plan stipulates that the residential sector and business and other sectors closely related to construction must reduce their CO₂ emissions by 66% and 51%, respectively in FY2030 compared with the FY2013 level.

To achieve this, effective use of natural energy sources that do not consume energy is necessary. In addition, because of the impact of the COVID-19 pandemic, people are spending more time at home owing to requests for priority measures to prevent the spread of the disease and the widespread use of remote work. This makes it important to prevent infection by opening and ventilating windows in homes and improving comfort.

In this study, we examined the ventilation performance of a wind catcher (WC) installed in a room of an apartment building and the indoor ventilation efficiency of window ventilation considering external wind by evaluating the ventilation volume, ventilation frequency, and air age distribution.

2. Measurement summary

The subject dwelling unit is on the fourth floor of an apartment building. The floor plan is shown in Fig. 1, and the shape of each opening is shown in Fig. 2.

Table 1. Study cases

<table>
<thead>
<tr>
<th>Combination of openings</th>
<th>Room-A (with wind catchers)</th>
<th>Room-B (without wind catchers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case1</td>
<td>Window1</td>
<td>Window5</td>
</tr>
<tr>
<td>Case2</td>
<td>Window3</td>
<td>Window7 and 9</td>
</tr>
<tr>
<td>Case3</td>
<td>Window9 and 13</td>
<td>Window1 and 6</td>
</tr>
<tr>
<td>Case4</td>
<td>Window1 and 2</td>
<td>Window4 and 5</td>
</tr>
</tbody>
</table>

If there is a difference in the ventilation performance of the WC window and Case 4, which does not use the part...
corresponding to the WC window, this difference is considered to represent the difference in the ventilation performance of Rooms A and B as a result of the difference in their arrangement.

The aperture velocity and pressure differences were measured during the field measurements. Ultrasonic anemometers were installed at each aperture as shown in Fig. 1 to measure the anemometer velocity at each aperture. Furthermore, a digital differential pressure gauge was used to measure the differential pressure between the indoor measurement point and each aperture measurement point, as shown in Fig. 1.

3. CFD analysis conditions

The analysis was first performed on a model that reproduced the surrounding city block centered on the subject building (L-model) as shown in Fig. 3, and the analysis then proceeded by sampling and data mapping the boundary conditions of the model with a reduced analysis area (S-model).

![Fig.3 CFD analysis area]

The analysis conditions are listed in Table 2.

<table>
<thead>
<tr>
<th>Turbulence model</th>
<th>L-model</th>
<th>S-model</th>
</tr>
</thead>
<tbody>
<tr>
<td>k-ε model</td>
<td>L-model</td>
<td>L-model</td>
</tr>
<tr>
<td>k-ε model</td>
<td>S-model</td>
<td>S-model</td>
</tr>
<tr>
<td>k-ε model</td>
<td>zero gradient</td>
<td>zero gradient</td>
</tr>
<tr>
<td>k-ε model</td>
<td>zero gradient</td>
<td>zero gradient</td>
</tr>
<tr>
<td>k-ε model</td>
<td>symmetry surface</td>
<td>symmetry surface</td>
</tr>
<tr>
<td>k-ε model</td>
<td>5.5 km/h, 5.5 km/h</td>
<td>5.5 km/h, 5.5 km/h</td>
</tr>
<tr>
<td>k-ε model</td>
<td>Realizable k-ε model</td>
<td>Realizable k-ε model, Durbin’s revised k-ε model and Realizable k-ε model</td>
</tr>
</tbody>
</table>

The realizable k-ε model was used for the L-model, the standard k-ε model was used for the S-model, the standard k-ε model with a built-in Durbin limiter and the realizable k-ε model were used for the turbulence model, and we performed a consistency comparison of the previous air age measurement and the present measurement results. The approach flow measured in a separate wind tunnel experiment was used as the inflow condition for the L-model. The wind directions in this study were 0°, 180°, 202.5°, and 337.5° based on actual measurements and wind direction from the Automated Meteorological Data Acquisition System (AMeDAS) (Fig. 4).

4. CFD analysis results

4.1 Comparison of field measurement and CFD results

It was confirmed that the actual measurements and computational fluid dynamics (CFD) results were in good agreement. The corresponding comparison results between the CFD analysis and measurement for each turbulence model are shown in Fig. 5. The standard k-ε model yielded the best correspondence with field measurements; therefore, the standard k-ε model was used in subsequent analysis with the S-model.

![Fig.5 Comparison of field measurement and CFD response]

4.2 Wind direction 0°(north)

No improvement in ventilation performance by WC was observed (Fig. 6).

![Fig.6 Ventilation comparison, wind direction 0°]

It was found that the wind speed on the south face where a WC was installed was small at a wind direction angle of 0°; therefore, the installation of the WC did not fully achieve the ventilation enhancement effect.

4.3 Wind direction 180°(south)

Fig. 7 shows a comparison of the ventilation rate for each case.

![Fig.7 Ventilation comparison, wind direction 180°]

From the results for Case 4, it can be judged that Room A previously had a higher ventilation performance than
room B.
Cases 1 and 3 exhibited a larger airflow in Room A. When no WC was installed because of the single-sided opening, the wind velocity at Window 6 was small and almost no inflow/outflow occurred, as shown in Fig. 9, whereas outflow was enhanced at Window 3-2 (Fig. 8).

In contrast, the wind direction on the south surface is easterly near the exterior wall because of the housing complex on the south side, and the negative pressure of WC enhances outflow at Window 3-2 in Case 3 (Fig. 10), indicating that the effect of WC is generally small in Room A because the flow from the south surface to the north surface is blocked, as demonstrated by Window 6 in Room B (Fig. 11).

**4.4 Wind direction 202.5°(south-southwest)**

The ventilation results are shown in Fig. 12. It can be observed from the figure that Room A is more ventilated in Cases 3 and 4. The separation in the northwest part of the subject building causes negative pressure on the north side as shown in Fig. 13, particularly on the Window 1 side of Room A, which enhances outflow from the north opening.

Therefore, the ventilation flow in Room A is larger in Cases 3 and 4, which have openings on two sides. In Case 1, which was not affected by the negative pressure on the north side, the installation of WC improved the ventilation performance of Room A because the inflow was stimulated by wind hitting WC at Window 3-2 (Figs. 14 and 15).

In Case 2, the effect of WC was small because the pressure drop at Window 3-1 in Room A is small, and the outflow did not significantly increase (Figs. 16 and 17).

**4.5 Wind direction 337.5°(north-northwest)**

Because of the difficulty in evaluating the improvement in the effect of the 337.5° wind direction owing to the effect of the separation that occurred in the southwest portion of the subject building, a model without WC was analyzed using CFD to compare the effect of WC (Fig. 18). In Cases 2 and 3, the effect of WC was minimal, and Room A was more ventilated than Room B owing to the effect of delamination (Fig. 19).

In Case 1, the pressure drop due to delamination affected Windows 3-1 and 3-2 without WC, and the pressure difference between the two windows decreased, resulting in low ventilation performance. The pressure difference between Windows 3-1 and 3-2 increased and the ventilation performance improved (Figs. 20 and 21).
5. Indoor ventilation efficiency study via CFD analysis

Considering that the opening/closing conditions of each window change based on the living conditions of the occupants, the indoor ventilation characteristics of a single opening, two openings on one side, and two openings on two sides were verified under two different wind directions (0° and 180°) based on field measurements and meteorological station data.

5.1 Wind direction 0°(north)

Fig. 22 shows the ventilation frequency results for each case, whereas Figs. 23 and 24 show the age of air distribution maps for each case. When only Window 3 was opened in the north wind (Case 1), air stagnation was observed on the north side of the room. The room near Window 3 was also not well ventilated because of short circuits. Air stagnation was significantly improved by opening the south veranda window. The ventilation frequency was approximately 2.5–4.0 1/h, which is not as high as that of the two-sided openings but is as good as the single-sided opening case on the leeward side. For the two-sided openings, the ventilation frequency was greater than 10 1/h, and the ventilation volume is sufficient.

In addition, because the room is surrounded by interior walls, it is difficult for fresh outdoor air to reach it, and stagnation was generally observed in the entrance area; however, this can be improved using a bathroom ventilation fan or a similar device.

5.2 Wind direction 180°(south)

Fig. 25 shows the ventilation frequency results for each case, whereas Figs. 26 and 27 show the age of air distribution maps for each case.

The ventilation volume of the south wind is larger than that of the north wind even with only Window 3 open (Case 1); however, air stagnation was observed in the
south side in Room B.
On the other hand, air stagnation was improved in the south side in Room A. When the south veranda window was added and opened, the ventilation volume should be similar to that of the two-sided openings, and in this case, the ventilation volume was larger in the WC retrofitted room. For the two-sided openings, the ventilation volume of Room B was larger in Cases 3 and 4. This could be as a result of the difference in the location of the rooms in the dwelling units. Another possible reason is the difference in the running area between the WC window and the sliding window in the south WC.

5.3 Effect of installing WC windows in different wind directions
In Sections 5.1 and 5.2, it was confirmed that even in the cases with the same opening, the trend of the age of air in the room differs depending on the wind direction. This was examined using the airflow characteristics near the wall of Window 3. Figs. 28 and 29 show the wind velocity vectors and pressure contour plots near Window 3 in the north and south wind directions, respectively.

Fig.28 Airflow characteristics in north wind
Fig.29 Airflow characteristics in south wind

The reference pressure is static pressure 59 m above the ground. It can be confirmed from these results that wind blowing up the south wall is from the north wind direction depending on the surrounding environment and building layout. In this case, the performance of the double-opening WC was poor, as presented in Section 5.1.

However, it can be confirmed that the south wind direction produces airflow that flows laterally on the south wall. In this case, it is considered that WC results in an increase or decrease in pressure, as presented in Section 5.2.

5.4 Performance Evaluation of a Renovated Room with WC
The effectiveness of the WC window was verified by dividing the ventilation volume of Room A (the WC retrofitted room) by the ventilation volume of Room B (before the retrofitting) in each wind direction at 16 azimuths. The results of Cases 1, 2, and 3 are shown in Fig. 30, which confirmed the effectiveness of the WC window at many wind direction angles; however, as mentioned in Section 5.3, the WC window exhibited the opposite effect in terms of improving ventilation at some wind direction angles. It was also confirmed that the effect of the WC window was most significant for a single opening and the effect was relatively small for two-sided openings.

6. Conclusion
The following conclusions are drawn based on the findings of this study.
1) Installing a WC in a single-sided opening enhances airflow in and out of the building and improves the ventilation performance.
2) The airflow around a building should be considered because installing a WC may prevent the original inflow and outflow.

References