Prediction of Cross-Ventilation Performance of Detached House Using Wind Catcher In Residential Buildings

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Abstract
With recent heat island phenomenon, it is an important issue to reduce the energy consumption of housing. As a countermeasure, there is a method to incorporate ventilation by installing a plate called a wind catcher. It is to improve the comfort of the room not only reduce energy consumption. Therefore, it is necessary to evaluate the performance of the ventilation accurately when you set up a wind catcher. For the evaluation of ventilation performance, it is generally used the ventilation flow rates. To do this, discharge coefficient is an important indicator. However, previous studies have not sufficiently consider discharge coefficient of openings installed wind catcher. So, this study considered discharge coefficient of openings installed wind catcher and the adaptability of local similarity model. As a result, the discharge coefficient of openings installed wind catcher is usually small than 0.67 that it of simple openings. Furthermore, it is possible to improve greatly prediction accuracy of ventilation flow rates of openings installed wind catcher by using the local similarity model.

Keywords - cross-Ventilation; wind catcher; wind tunnel experiment; computational fluid dynamics; discharge coefficient; local dynamic similarity model

1. Introduction
"Kyoto Protocol" in COP3 in 1997 was adopted. It must reduce the 6% of the greenhouse gas in 2008 to 2012 in Japan. However, it was reduced in 2009, it continues to grow after 2010. It is necessary to reduce the energy consumption of housing. As a countermeasure, there is a method to incorporate ventilation by installing a plate called a wind catcher. It is to improve the comfort of the room not only reduce energy consumption. Previous studies have shown that it is to improve the ventilation performance by installing a wind catcher in openings. For the evaluation of ventilation performance, it is generally used the ventilation flow rates. To do this, discharge coefficient is an important indicator. However, previous studies have not sufficiently consider discharge coefficient of openings installed wind catcher. So, this study considered discharge coefficient of openings installed wind catcher. Further, previous studies have not sufficiently consider the adaptability of local similarity model (model to change discharge coefficient by taking into account the tangential
direction dynamic pressure of openings) when installed wind catcher. So, such as the adaptability of local similarity model, this study considered prediction method of ventilation flow rates when you set up a wind catcher.

2. METHODS

In order to grasp the nature of the ventilation air flow, there are two ways of wind tunnel experiments and CFD analysis is roughly classified into. Wind tunnel experiments requires knowledge and enormous amount of time to a variety of equipment, but the results I obtained close to the actual phenomena. On the other hand, CFD will be able to consider a number of cases in a short period of time, but the air flow and pressure can be visualized, it is concerned about the accuracy of precision. In this study, we examined using both methods.

(1) Wind Tunnel Experiment

First, we had a wind tunnel experiment. We were using a standard residential model of Udagawa. Approach flow has a profile in accordance with the fourth law of assuming the city. Density of the surrounding buildings are organized gross building coverage, 30%, 40%, and 50%. Experimental cases are one side opening 3 cases (Case A), face-to-face openings 3 cases (Case B), and adjacent opening 4 cases (Case C). Measurement items are ventilation quantity measured in tracer gas constant generating method, air velocity measurements between neighboring building with split film was the opening wind pressure measured by chamber pressure. Wind direction angle are four wind directions, 0 °, 90 °, 180 °, and 270 °.
We compared discharge coefficient of simple openings with openings installed wind catcher. The pressure difference calculated by the pressure measurement by chamber pressure, and compares calculated ventilation of simple openings discharge coefficient 0.67 at ventilation volume and a constant generation technique that was calculated using.

\[
Q = \alpha \frac{\rho}{\sqrt{\Delta P}} | \Delta P |
\]  

(1)

where \( Q \) is ventilation flow rates \([\text{m}^3/\text{s}]\), \( \alpha \) is discharge coefficient \([\text{l}]\), \( A \) is opening area \([\text{m}^2]\), \( \rho \) is density \([\text{kg}/\text{m}^3]\), and \( \Delta P \) is inside and outside of the pressure difference \([\text{Pa}]\).

(2) Discharge Coefficient (CFD)

In this section, a comparison study of simple openings for openings of the parameters installed wind catcher using a chamber model. It is 4 cases of inflow, outflow, without wind catcher, and with wind catcher.

It shows a method for calculating discharge coefficient.

\[
\alpha = \frac{Q}{A \sqrt{\rho | \Delta P |}}
\]  

(2)

It shows a method of calculating scaled chamber pressure.

\[
P_f, \quad P_v, \quad P_w
\]  

(3)
(3) Prediction Accuracy of Ventilation Flow Rates (CFD)

We have examined method evaluating ventilation performance of housing installed a wind catcher in CFD analysis. We used ventilation flow rates as an indicator. Target building was using same model as it of experiment. Analysis subject is a second floor. We used the cycle boundary as a boundary condition to reproduce the city. We used mass flow rate based on the 1/4 power law, and wind speed of the eave height was 1.00[m/s].

We compared ventilation flow rates calculated in three ways.
1. Ventilation amount solved across, including the room. This is ventilation flow rates in CFD analysis.
2. Ventilation flow rates calculated by applying the local similarity model to calculate discharge coefficient. Pressure difference is results of CFD analysis.
3. Discharge coefficient is 0.67 of simple openings. Pressure difference is results of CFD analysis.

(4) Indoor Air When Installing Openings a wind Catcher (CFD)

From the results of a previous section, it improves cross-ventilation performance by placing two wind catcher face-to-face opening. However, air flow characteristics of rooms will vary greatly depending on position of openings. It is not necessarily flowing through air flow throughout rooms even in openings ventilation flow rates is large. In this section, in cases face-to-face openings used two wind catchers, we considered changes in the indoor air flow by changing position of openings. In this chapter, we investigate by using a domain decomposition method. And we used the local similarity model from results by shield model used in CFD analysis of a previous section.
3. RESULTS AND DISCUSSION

(1) Wind Tunnel Experiment

It does not cause much difference in cases ventilation flow rates is small, wind direction angle is 0° and 180°. But in cases large ventilation flow rates of wind direction angle is 90° and 270°, ventilation flow rates that discharge coefficient is fixed at 0.67 is larger than experimental ventilation flow rates. The reason for this is tangential direction of dynamic pressure of openings is small in cases that wind direction angle is 0° and 180°, and discharge coefficient is same as it of simple openings. Angential direction of dynamic pressure of openings is large, and it improves cross-ventilation performance by installing a wind catcher. Furthermore tangential dynamic pressure effects on pressure loss in periphery of openings. Thus, prediction of ventilation flow rates when installing a wind catcher, it is necessary to grasp discharge coefficient of openings installed wind catcher. Furthermore, in order to carry out a study with the local similarity model, it is necessary to consider parameters of openings installed wind catcher.
(2) Discharge Coefficient (CFD)

When the chamber flow rate is 0.3 to the range from -10 to 0, wind catcher there acts strongly pressure by air flow striking the wind catcher in the case of, but slightly larger than without wind catcher, from the opening of the indoor side pressure distribution can be seen that are generally consistent with cases without wind catcher. In addition, but when the chamber flow in the range of -10 below 2.0, the opening pressure distribution is substantially coincident with without wind catcher and with wind catcher, little influenced by pressure by the air flow collides with wind catcher. Therefore, There is wind catcher in the range from -10 to 0, but the influence of the pressure caused by the air flow collides with wind catcher is slightly larger than without wind catcher, wind catcher has openings pressure distribution without wind catcher matches, the air flow structure of openings or without wind catcher is considered unchanged. This is consistent relationship with wind catcher or without wind catcher, in consideration of the later, it is assumed that performs consider using a simple openings of the parameters even if there is wind catcher.

![Fig. 10 Relationship of the chamber pressure and discharge coefficient](image)

(3) Prediction Accuracy of Ventilation Flow Rates (CFD)

In any opening cases, ventilation flow rates calculated in discharge coefficient fixed as 0.67 are overestimated the ventilation quantity. However, it is in good agreement with the results of the relatively entire calculation even if gross building coverage and wind direction angle, the installation position of the wind catcher changed in case of calculating the ventilation amount of the local similarity model. This is also discharge coefficient of the aperture becomes 0.67 or less in which the opening cases, it is thought to be due to that can reproduce discharge coefficient of openings installed wind catcher by the local similarity model. Thus, by using the local similarity model, it was found that it is possible to predict ventilation flow rates in the case of installing a wind catcher. Moreover, comparing ventilation flow rates of each
opening cases, it can be seen that ventilation flow rates increases in case B3. Many wind direction angle of the installed two of wind catcher. We considered two of the wind catcher in case B3 is because it has demonstrated the ventilation promoting effect.

(4) Indoor Air When Installing Openings wind Catcher (CFD)

It shows the results of analysis of three cases of face-to-face openings. When you number the installation of 2 wind catchers, it can be confirmed that the mean wind speed and the chamber of the ventilation amount is best.

It shows a comparison of the occupied zone average wind speed and ventilation flow rates of each opening cases. Ventilation flow rates is reduced in the case B3_7, not seen much difference in other cases. In addition, residential area average wind speed increases the wind speed in the case B3_1 and B3_5, wind speed is reduced in case B3_2 and B3_7.
Indoor airflow distribution of each opening case it is shown in Figure 6.3.3. The openings cases like B3_2, air flow from the inlet opening to towards the outlet opening along the wall, it is believed that the occupied zone average wind speed not spread the air flow in the room is small. In the occupied zone average wind speed is greater B3_1 and B3_5 case, it is understood that the swirling flow is generated in the chamber as shown in Figure 6.3.4. Thus, air flow flows through the entire chamber by the swirling flow is generated, it is believed to enhance the residence zone average wind speed.

4. CONCLUSIONS

(1) Discharge coefficient of openings installed a wind catcher is smaller than it of simple openings.
(2) Relationship to Discharge coefficient and scaled chamber pressure P_R* does not change substantially with wind catcher and without wind catcher.
(3) By applying the local similarity model, prediction accuracy of ventilation flow rates when installed the wind catcher is improved.
(4) When facing the opening, thereby improving the ventilation performance of the chamber by increasing the opening for installing the wind catcher. Furthermore, the installation position of the wind catcher, it is possible to change the room air flow.

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