PREDICTION OF INFLOW DIRECTION AT LARGE OPENING OF CROSS VENTILATED APARTMENT BUILDING

Hitoshi KOTANI* and Toshio YAMANAKA**

1. Introduction

Cross ventilation has been studied for long time by many researchers, especially Japanese researchers have been interested in this topic because the cross ventilation is common used in Japan to improve the indoor thermal environment in hot summer season. Recently the members of EIA/EIES Annex 35 (I activities) have been conducting energetic researches and many useful results have been obtained as well.

In case of cross ventilation through the large opening, it is well known that the cross ventilation makes a flow contact of a windward and leeward openings as shown in Figure 1. In this situation, the use of general discharged coefficient (CD) value is not suitable for the calculation of cross ventilation rate. The total pressure loss coefficient of the room (Σ) becomes smaller than the correction of the pressure loss coefficient of an opening in series (CD). CD value is the reciprocal of square root of Σ, so the calculation by CD value under-estimates the cross ventilation rate. To deal with this decrease of pressure loss coefficient, Ishihara [6] proposed “interference factor”, which is the ratio of Σ to Σ.

Secondly, the pressure loss coefficient of CD value of an opening varies with the inflow direction, and the use of normal values over-estimates the airflow rate. Ishihara [7] also showed the experimental data and Σ becomes larger in case of the larger portion of two openings.

Many researchers are supporting these two tendencies of the pressure loss coefficient [8]. More detailed reviews about this problem are seen in Kambuchi and Ohba [9].

Although there are many researches from the above-mentioned viewpoint, there used to be few researches to develop the simple but reasonable prediction method of the cross ventilation rate. Recently, Komuchi et al. [10] tried to reveal the mechanism of cross ventilation using CFD and proposed “Local Dynamic Similarity Model of Cross Ventilation” as the systematic prediction method of flow rate. This paper, reasonable and systematic prediction method of the cross ventilation rate through large

Fig. 1 Flow contact between two openings and the use of total pressure loss coefficient instead of pressure loss coefficient of an opening.
This needs to be measured, but the authors have already had many measured data for various building shapes. Further research is now planning to prepare the reasonable function of this wind velocity. The wind velocity normal to the opening is the value which is the resultant airflow rate (Q) divided by opening area (A). The initial value of Q is calculated by the simple orifice equation and the wind velocity and total pressure loss coefficient of room \( \xi \) are calculated simultaneously by iteration. Cp values are used in the orifice equation and Cp values should be measured as well, but authors have made a regression function for the various building shapes in the previous research. Though this calculation needs the iteration, it is not so complicated by the use of simple vector composition. The practical use is intended and the use of the values parallel and normal to the wall is easy.

### 2. Simultaneous calculation of inflow direction and airflow rate

As mentioned above, it is well known the pressure loss coefficient \( \xi \) of an opening varies with the inflow direction. Kominato et al. have made experiments to know \( \xi \) under various opening sizes, room sizes and wind directions. It was found that \( \xi \) also varies according to the inlet wind direction. Therefore, the authors propose the simultaneous calculation method of inflow direction and airflow rate. Figure 2 shows the procedure of the airflow rate. At first, outdoor wind direction, building shape and room condition (location and dimension) inside the wind pressure coefficient \( C_p \) and the wind velocity parallel to wall \( (v_w) \). Secondly, inflow direction at the opening \((\theta)\) is derived from \( v_w \) and airflow rate \((Q)\). Here, the pressure loss coefficient \( \xi \) of the room \((Q)\) by the empirical relation between these two values at the certain condition of opening dimension and room dimension. \( Q \) can be calculated by \( \xi \) and wind pressure difference \( P \) obtained from \( C_p \) and \( v_w \).

Finally, \( \theta \) and \( Q \) are calculated by iteration. In the method, following data for different conditions are needed in advance:

- \( C_p \) value, \( v_w \) value, \( (\xi) \) relationship between \( \theta \) and \( Q \).

The new concept and the core of this method is the prediction of inflow direction at the opening by use of vector composition of the wind velocity parallel to the wall and normal to the opening as shown in Figure 3. The wind velocity parallel to the wall is the velocity in front of the opening, when the opening is closed. It is reasonable to use this velocity when the opening is relatively small compared with the whole building wall.
As a result, the pressure loss coefficient of the room \( \delta \) at the various inlet wind directions was calculated by general orifice equation. Table 1 and Figure 5 show the experimental conditions; two angles for the plane parallel to opening (azimuth) and five inlet wind directions were used. That is to say, this is the limit of application and the validation of this method when the following relationship is used. The relationship between inlet wind direction and total pressure loss coefficient by previous measurement and its regression functions are shown in Figure 6. In this relationship, the pressure loss coefficient of the guide for wind direction in Figure 4 is not included and the ratios of inlet pressure loss coefficient without the guide are compensated. For different situation of the opening and room location of this measurement, for instance, (1) the opening sizes are different, (2) opening location is curved or (3) openings are not located at the opposite wall, authors already have obtained the relation between inlet wind direction and total pressure loss coefficients.

3. Wind tunnel test

The wind tunnel tests using a three-storied apartment building model with a room were conducted to investigate the inflow direction and the flow rate at the opening. The room with the opening can be set at the different nine positions. Figure 7 and Figure 8 show the apartment model and the setup situation on the floor of the wind tunnel of which approaching flow is the atmospheric boundary layer of 1/5 power law. Figure 9 shows the wind tunnel geometry and the approaching wind-profile is shown in Figure 10. The large-scale turbulence is generated by the lattice, and the roughness elements on the tunnel floor make the small-scale turbulence and the boundary layer. The reference external wind velocity is 10 m/s at 1000 mm height from the tunnel floor. The combination of the room positions and the external wind directions make various inflow directions at the inlet opening.

The wind velocities parallel to the wall in front of the position where the openings locate were measured by constant-temperature hot-wire anemometer during 30 seconds with its sampling frequency of 250 Hz as shown in Figure 11. The measuring points were set at the 3 mm in front of the wall. It was checked that this points locates inside the boundary layer of the wall by preliminary velocity measurements except for the case that the measuring position locates inside the wake or the

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8 24, 34, 45, 67.5, 80

<table>
<thead>
<tr>
<th>Inlet wind direction (deg)</th>
<th>0, 22.5, 45, 67.5, 80</th>
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<tbody>
<tr>
<td>Opening test</td>
<td>0, 22.5, 45, 67.5, 80</td>
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Fig. 5 Setting of azimuth and inlet direction for chamber method (see Table 1)

Fig. 6 Relationship between inlet wind direction \( \theta \) and total pressure loss coefficient \( \Delta p \).

Fig. 7 Wind tunnel model of the three-storied apartment building with large opened room.

Fig. 8 Wind tunnel setup.

Fig. 9 Wind tunnel geometry.

Fig. 10 Approaching wind profiles.
The Cp values were obtained by the measurement of the wind pressure at four small holes of 2-mm square where the openings located as shown in Figure 11. The wind pressures were measured by manometer during 30 seconds with its sampling frequency of 100 Hz and those averaged values at each opening position were calculated. The dynamic pressure at the building height (384 mm) is calculated from the value at 1000 mm above wind tunnel floor by pitot tube as shown in Figure 9 as the reference value for Cp. It should be noted that the measurements of the wind velocities parallel to the wall and Cp values were conducted under the situation that openings were closed.

The inflow direction and wind velocity at the inlet openings were measured by constant-temperature hot-wire anemometer with split film probe during 30 seconds with its sampling frequency of 100 Hz. This anemometer can measure the wind velocity and wind direction at the same time. This anemometer has split line between two films and the wind direction can be judged by the comparison of the output signal from these two films. The calibration for wind direction and wind velocity should be carried out in advance for obtaining the two components of the wind vector on a certain plane. However, to obtain the nominal vector of the opening as shown in Figure 12, velocity vectors on the vertical and horizontal plane should be measured and these vectors compose three dimensional vector. Therefore two different setups of probe are needed (see Figure 13). Figure 14 shows the measurement accuracy of anemometer for the wind direction. In the case that the wind direction exceeds 60°, the accuracy decreases and some impossible cases of measurement will occur in a certain wind velocity condition. Therefore the reliance of the data when the inflow direction exceeds 60° is not high but data is presented as information in the following discussions.

As the purpose of this research focuses the validation of the proposed calculation method, the experimental parameters were limited. Nine room positions and five external wind directions of 0°, 22.5°, 45°, 67.5° and 80° degree were selected as shown in Table 2.

4. Wind velocities parallel to the wall and Cp values

Figure 15 shows the measurement results of the wind velocities parallel to the wall. The reference wind velocity for the dimensionless velocity is set at the building height (384 mm). At almost all positions, the increment of the external wind directions leads to the increment of the wind velocities. This can be explained by the acceleration of the wind velocity according to the increment of the distance from the stagnation point of the building. At room 3, 6, and 9, lower wind velocities are shown when the external wind direction of 22.5 degree. The reason is that these rooms locate at the windward position and expect to be near the stagnation area when the wind direction. This is the same tendency at room 2, 5, and 8 at the wind direction of 0 degree. In case that the external wind direction is 80 degree, the external flow is separated by the sidewalk of the building and the measuring points locate inside the wake so the wind velocity decreases.

Figure 16 shows the difference of wind pressure coefficient between, windward and nesward opening position (i.e. Cp). These results seem to be the reverse curve to wind velocity parallel to the wall (Fig. 14) in almost all
cases. This can be understood from the viewpoint that the Bernoulli's theory along the wall was realized.

These velocities and ΔCp values will be used as the input of the proposed calculation method.

Fig. 16 Relationship between external wind direction and difference of Cp values

5. Inflow direction at the openings

Figure 17 and 18 show the measured results of the inflow vector at the opening. In this measurement, the building was not sealed and the room opening was opened. Though these figures show the results of nine rooms in one figure, it should be noted that these were measured separately and the experiments were made to know the inflow direction in the case that only one room is set in the building. In some cases, the vectors were not drawn due to the low accuracy of the anemometer.

These vectors show that the inflow direction at the opening is not normal to the opening. Only if the opening locates at the stagnation point of the building, the inflow direction is expected to be normal to the opening. In case that the external wind direction is 90 degrees, openings seem to be inside the wake or separation area of the building, so the velocities became small and the inlet direction came close to the normal to the opening. As for the same wind direction (90 degrees), values of ΔCp of room 3, 6 and 9 show negative values or almost zero in Figure 16, so the outflow can occur at some positions inside the opening or there can be the measurement errors of ΔCp. From the vectors on a vertical plane, it is suggested that the vertical stagnation point of the building locates between the second floor and the third floor at every external wind directions. As for the horizontal stagnation points, it is dependent upon the external wind direction.

These figures were measured from the viewpoint of the flow around and along the building.

Fig. 17 Inflow vectors on vertical plane at openings

Fig. 18 Inflow vectors on horizontal plane at openings
6. Comparison with calculated results using the proposed method

The prediction of inflow direction as mentioned above was conducted using measured the wind velocities parallel to the wall and Cp values. Figure 19 shows the way to obtain the normal vector to opening from the vertical and horizontal vectors as shown in Figure 17 and 18 that should be compared with predicted inflow directions.

Figure 20 shows the measured inflow direction (see Figure 17 and 18) and calculated one. Plots show the measurement direction and the lines are the calculated ones. There are some lacks in the measurement results.

Though the errors are very large in case that the external wind direction is 60 degree, they are in good agreement. 80 degree of the wind direction means that the openings locate inside the wake or separation area, so the different mechanism of the ventilation can occur like pulsation or turbulence diffusion. It should be also noted that the relevance of the data when the inflow direction exceeds 60 degree are not high and the accuracy of the measurement decrease unavoidably in case of the low velocity.

This result supports that the proposed calculation method has enough accuracy of the prediction of the inlet wind direction at the opening in the most parts of the external wind directions of from 0 to 45-degree.

Acknowledgment

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References
1. はじめに

従来の風化量子化に関しては、古くから日本の研究者によって研究がなされ、また近年ではJQIのDNC Annex 35の研究グループにより、精力的に研究が行われている。

一般に風化皮膜の風化現象に、全体の風化損失係数は、壁面あ


2. 流入角と流速の制限条件

図2に示すように、従来の流れの風化損失係数に関する研究では、従来、これは


3. 流速流れ

流入口での流れ角は、スプールフィルムとプールを有する熱


4. 境界近似条件の風速および風向極値

図15に、境界条件の風速と風向極値を示す。多くの研究において、


5. 間断における流入条件

図14に、間断が入った風速での風速の風向の極値を示す。


6. 昇降力の計算にとる計算

従来の流速流れの計算では、従来の風速の流速流れの算定を用


7. 結論

流入角と風速流れの計算方法を提案し、流入角の極値条件により


8. 付録

流入口の計算方法の詳細を示す。従来の流入角の極値条件により、


本文終了

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