Enhancement of cross-ventilation of a detached house using roof surfaces in densely populated urban areas Part1 Wind pressure distribution by wind tunnel experiment

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ABSTRACT

In Asian countries under sultry climatic conditions including Japan, natural ventilation and cross-ventilation at nighttime give very good effects on the improvement of physical conditions of the residents and on the cooling of the buildings in intermediate and summer seasons. However, a densely populated urban area such as Tokyo, sufficient ventilation flow rate may not be necessarily maintained because the distances between neighboring houses are shorter and also because of the problem to keep privacy of the residents between the windows, which are positioned face-to-face on wall surfaces. In Part 1 of the present study, it is attempted to perform wind tunnel experiment to evaluate the changes of wind pressure coefficient on the buildings when gross building coverage ratio is changed, and assessment is made on the possibility to effectively utilize the results of the study of cross-ventilation on roof surfaces in the densely populated urban area. The results of the study suggest that, in case the openings are installed on roofs, better effects can be expected on roof surfaces than the case where the openings are installed on wall surfaces.

1. INTRODUCTION

The year 2008 will be the year to start the execution of the agreement of the Kyoto Protocol, and energy-saving efforts are now being made in various social fields. In Japan, about 30% of total discharge quantity of carbon dioxide (CO_2) come from the building engineering and house construction industries. In this sense, much expectation is now put on those who are engaging in the works related to building and house construction, and, in particular, on those who are specializing in the study of building environment and facility engineering. Under the influence of such circumstances, there are now tendencies to try to obtain the effects of night purge and the physical comfortableness of the residents by opening the windows at nighttime and by introducing natural ventilation in intermediate and summer seasons. Currently, fervent efforts are being made in Japan on the accurate evaluation of ventilation flow rate. The present authors have also proposed Local Dynamic Similarity Model (hereinafter referred as "LDS-Model"), and there have been diverse responses and schemes to this proposal. Most of these schemes relate to the evaluation based on the condition where surrounding areas of the buildings are opened. In the densely populated urban area such as Tokyo, it is known that external airflows to reach the buildings are weakened and the wind pressure coefficients are decreased. Under such circumstances, the problems in future lie in such issues that what kind of efforts should be made for the purpose of increasing the ventilation flow rate. In this respect, evaluation is performed in the present study as to how far it would be possible to maintain ventilation flow rate in the densely populated urban area by effectively utilizing the skylight, which was originally installed for the purpose of introducing better lighting, by using wind tunnel experiment.

2. OUTLINE OF THE STUDY

2.1 General features of wind tunnel experiment

For the experiment, the wind tunnel facilities owned by Tokyo Polytechnic University were used. At first, as the preparation to perform evaluation on the reproduction of the densely populated urban area, all roughness blocks were removed. Measurement was made the approaching flow and building models with exactly the same configurations as those of the buildings under study were installed by placing them in the wind tunnel. Wind velocity measuring points of the approaching flow and the building arrangement are shown in Fig.1. Next, the approaching flow was measured when normal type roughness blocks were placed in the upstream portion of the wind tunnel (Fig.2), and it was assessed how far the reproduction should be made on the surrounding area of the buildings under study in the same type of experiment. The results are shown in Fig.3. When normal roughness blocks were placed on the portion up to 2 m immediately in front of the building under study, the approaching flow was almost the same. Therefore, in the evaluation as given below, the study was made only on the surrounding area of the building under study when buildings and building coverage ratio were changed.

2.2 Measurement of wind pressure coefficient distribution
For the purpose of studying wind pressure coefficient distribution on the detached house built in the densely populated urban area, wind tunnel experiment was carried out by changing gross building coverage ratio (hereinafter referred as "building coverage") to 0%, 10%, 20% and 40% as shown in Fig.4. The configurations of the buildings under study were divided to three types shown in Fig.5.

2.3 Local dynamic similarity model
For the prediction of ventilation flow rate, the LDS-Model (Kurabuchi, 2005) as proposed by the present authors was used. Fig.6 shows general concept of the model and the parameters are summarized in Table1. The LDS-Model is a model to explain the changes of discharge coefficient on the openings at the time of ventilation based on dynamic similarity of airflows on and

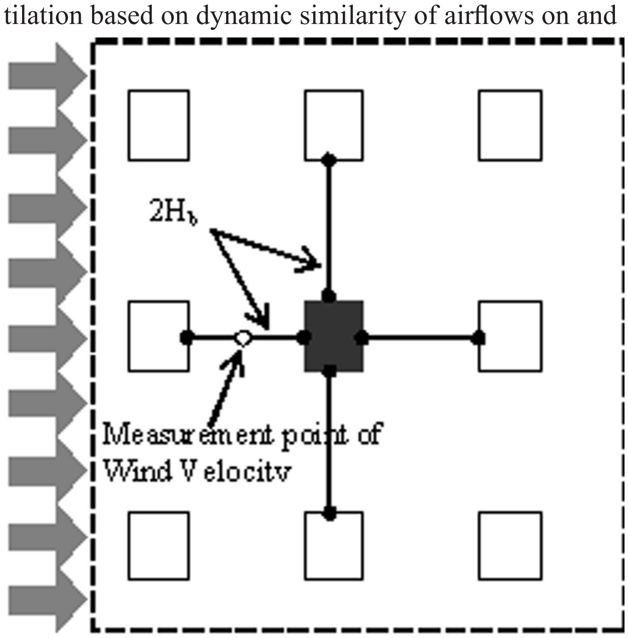


Figure 1: Building arrangement

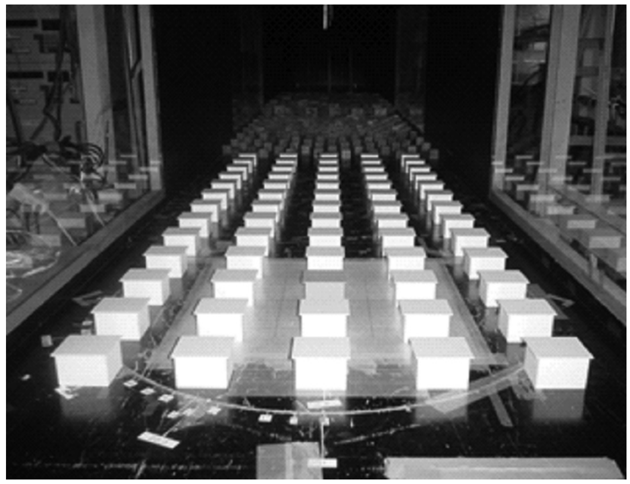


Figure 2: Building models were only placed surrounding the target building.

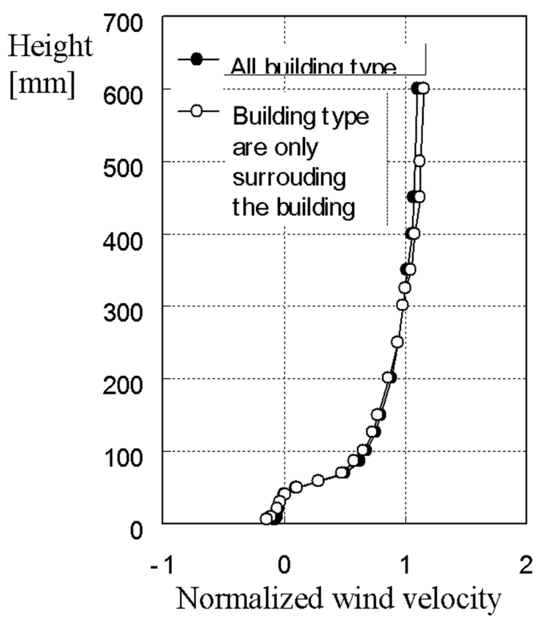


Figure 3: Wind velocity profile (U)

around the openings. Discharge coefficient is uniquely determined by dimensionless room pressure P_R^*. The discharge coefficient (C_d) can be accurately identified from wind pressure (P_W) applied on the openings, dynamic pressure tangential to the opening (P_t), and room pressure (P_R) by preparing P_R^*-C_d curve in advance for each of opening configurations as shown in Fig.7 or by referring to the articles already reported. Here, the room pressure P_R is a value, which cannot be determined if the ventilation flow rate is not known. Accordingly, an adequate numerical value is given as the initial value in the calculation of ventilation network model, and by regarding P_R as an unknown value, C_d is changed and ventilation flow rate is calculated. Then, this procedure is repeated. By repeating the calculation up to convergence (up to the time when flow rate on the inflow side is to be identical with that of the outflow side), and the ventilation flow rate can be calculated with higher accuracy than in the conventional method (Equation 1). In the present report, the ventilation flow rate based on the LDS-Model was calculated by the procedure as given above.

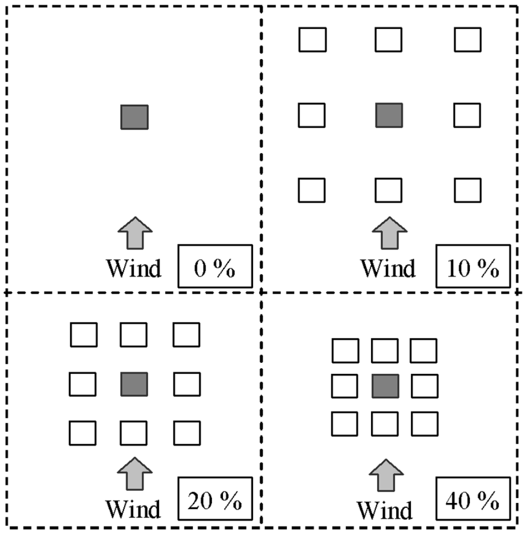


Figure 4: The building coverage idea

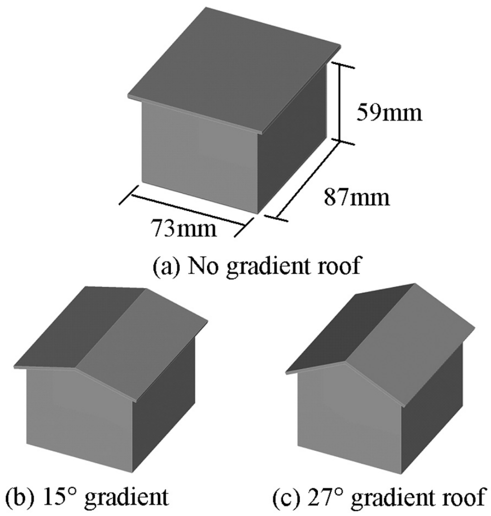


Figure 5: The buildings under study

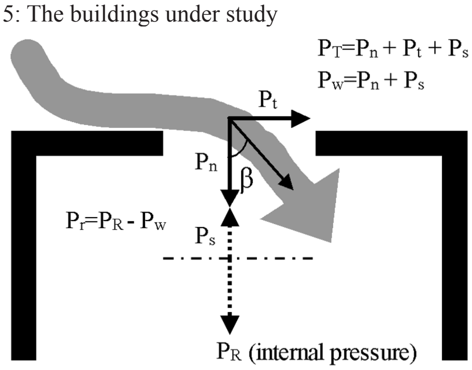


Figure 6: Airflow condition around inflow opening

$$Q = Cd * A\sqrt{\frac{2}{\rho}(P_W - P_R)} \tag{1}$$

Table 1: Basic components of LDS-Model

$$P_r = P_R - P_W \qquad P_R^{\ *} = \frac{P_r}{P_t} \qquad C_d = \sqrt{\frac{P_n}{|P_r|}}$$

$$Q = A \times C_d \sqrt{\frac{2}{\rho}|P_r|} \qquad \beta = tan^{-1}\sqrt{\frac{P_t}{P_n}}$$

Pr: ventilation driving force PR: room pressure
PW: wind pressure PR*: dimensionless room pressure
Pt: dynamic pressure tangential to the opening
Cd: discharge coefficient Q: cross-ventilation flow rate
Pn: dynamic pressure normal to the opening
A: area of opening ρ: density of air β: inflow angle

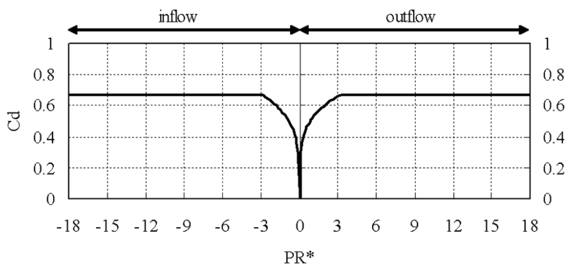


Figure 7: Relation between PR* and Cd (PR*-Cd curve)

3. RESULTS AND DISCUSSION

3.1 Wind pressure coefficient distribution

Fig.8 shows wind pressure coefficient distribution on each of the buildings. It is evident from the figure that, on any of these buildings, wind pressure coefficient on windward surface is high and approximately in the range of 0.6 to 0.8 when building coverage is 0%, and negative pressure is generated on leeward surface and the value is about -0.2. This indicates that, when building coverage is 0%, there is high possibility that sufficient cross-ventilation can be attained even when the openings are installed between wall surfaces. With the increase of building coverage, the difference of wind pressure coefficients between wall surfaces is decreased. When building coverage is 40%, wind pressure coefficient is turned to nearly 0 on both windward surface and leeward surface, and this suggests that it is difficult to maintain ventilation flow rate between the openings, which are installed on the wall surfaces. In contrast, when the values of wind pressure coefficients on roof surfaces are compared with each other, the value of wind pressure coefficient changes with the increase of building coverage, but the range of the change is smaller,

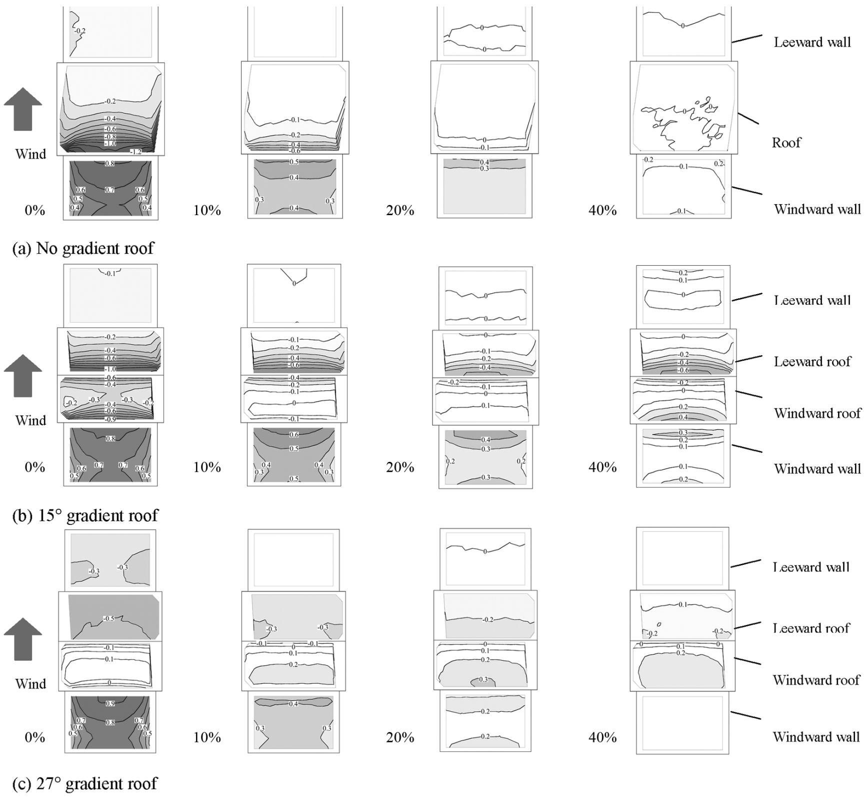


Figure 8: Wind pressure coefficient distribution

and this reveals that the roof surface can be effectively used. Here, as shown in Fig.9, assumption is made on ventilation route in 5 cases, in which typical opening installation pattern and roof surface are applied on each building. Fig.10 shows the difference of wind pressure coefficients at the estimated positions of the openings. As described above, it is evident that the difference of wind pressure coefficients between wall surfaces greatly decreases with the increase of building coverage. Also, the difference of wind pressure coefficients decreases with the increase of building coverage when roof surfaces are utilized, but it is not so conspicuous in comparison with the case between wall surfaces. When building coverage is 40%, the difference of wind pressure coefficients in case where roof surfaces are used is higher than the case between wall surfaces. In particular, in the case as given above, the difference of wind pressure coefficients is maintained at higher level than the case between wall surfaces, and this indicates the possibility that it may be a highly effective ventilation route.

3.2 Change of building coverage and prediction of ventilation flow rate

The ventilation flow rate was predicted by using skylight (Fig.11), which has been reported as effective in the evaluation of ventilation at skylight in a previous study (Nonaka, 2007). Dynamic pressure tangential to the opening when wind pressure coefficient was measured as described above was determined by split film probe, and the result was converted to dynamic pressure, and this was defined as P_t. As the boundary conditions, wind pressure P_W at the position of the opening, tangential dynamic pressure P_t, and P_R^*-C_d curve of skylight and normal type window (Nonaka, 2007) were used, and the room pressure P_R was obtained by calculation of ventilation network model so that the ventilation flow rate on the inflow side will be identical with the value of the ventilation flow rate on the outflow side (For details, see: Endo, 2006). Fig.12 shows the changes of the predicted ventilation flow rate. Similarly to the transition of the difference of wind pressure coefficients, it is found that ventilation flow rate also decreases with the increase of building coverage. In particular, when openings are installed between wall surfaces, it is turned to a value about 50% lower than the case where roof surfaces are used with the building coverage at 40%. These results suggest that it is the most effective for maintaining the ventilation flow rate at any building coverage if the openings are installed on windward surface and leeward roof surface after conducting the preliminary investigation of main wind direction at the place where the buildings are scheduled to be constructed.

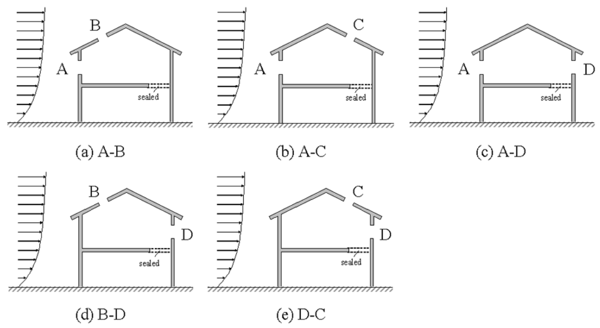
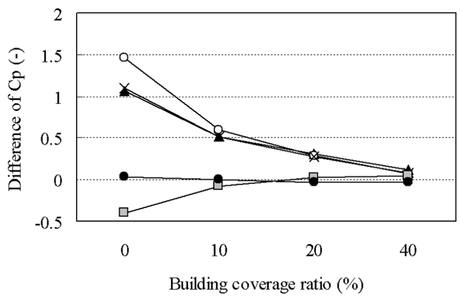
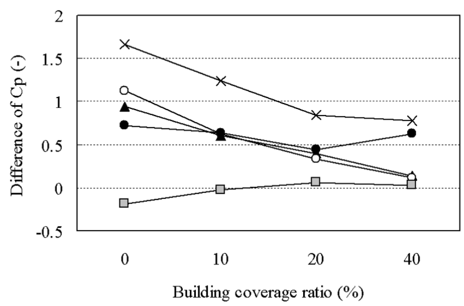


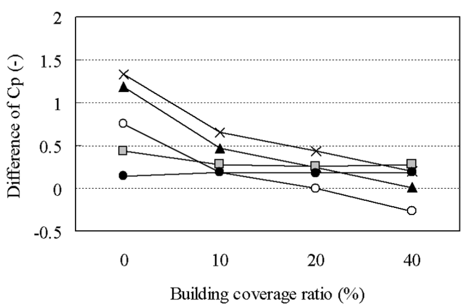
Figure 9: Installation pattern of the openings



(a) No gradient roof



(b) 15° gradient roof



(c) 27° gradient roof

? A-B ×A-C ? A-D ? B-D ? D-C

Figure 10: Relation between building coverage and difference of wind pressure coefficients

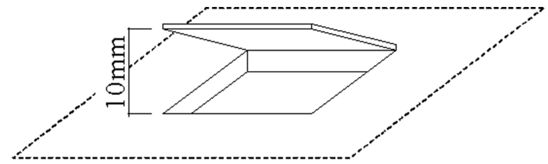
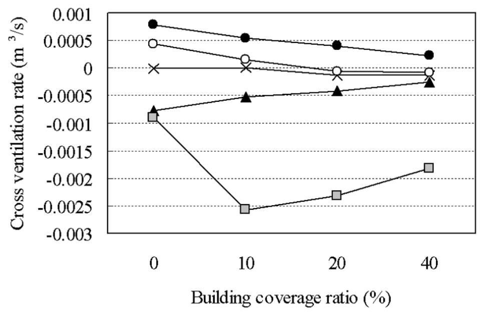
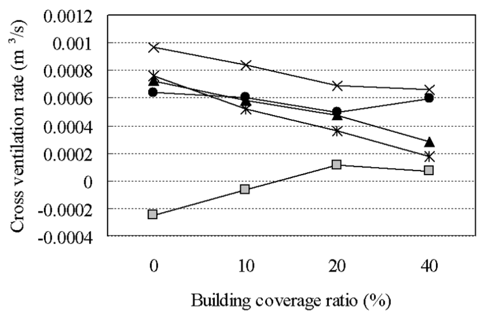


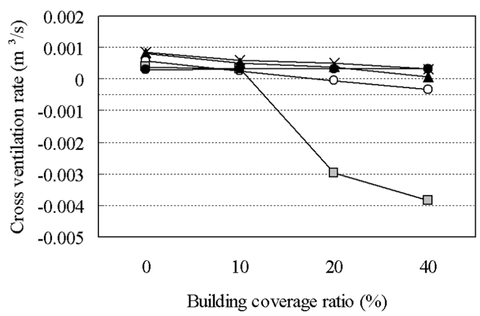
Figure 11: Type of skylight



(a) No gradient roof



(b) 15° gradient roof



(c) 27° gradient roof

? A-B ×A-C ? A-D ? B-D ? D-C

Figure 12: Prediction of the changes of cross-ventilation flow rate associated with the changes of building coverage

4. CONCLUSIONS

In the present study (Part 1), wind tunnel experiment was conducted by assuming a densely populated urban area, and evaluation was made on the changes of wind pressure coefficient distribution, which occurs due to the changes of gross building coverage, on buildings at the center of urban area. As a result, it is suggested that, when building coverage is closer to 40%, it is difficult to maintain sufficient ventilation flow rate between wall surfaces while roof surfaces can be effectively utilized, which shows lower changes of wind pressure coefficient. Next, ventilation network model was calculated by incorporating the LDS-Model and ventilation flow rate was predicted by using wind pressure coefficient distribution obtained from the experiment. Similarly to the transition of the difference of wind pressure coefficients, ventilation flow rate decreases with the increase of building coverage while it is found that higher ventilation flow rate can be attained when ventilation route pattern using roof surfaces is used than the case where ventilation route pattern between wall surfaces is used with the building coverage at 40%. Thus, the behaviors in effective utilization of roof surfaces and in the transition of wind pressure coefficient distribution in the densely populated urban area could be accurately identified. However, when there are changes in the buildings under study or when building coverage differs, it is necessary to obtain wind pressure coefficient by conducting wind tunnel experiment each time, and this is not very economical. In this respect, in Part 2 of the study, evaluation was made on the method to reproduce the densely populated urban area by using CFD as an alternative method to the wind tunnel experiment.

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