A Study on Wind Pressure Coefficients of Residential Buildings and Simplified Prediction of Air Change Rate by Cross-Ventilation

Y. Akamine, Y. Sakamoto, M. Mae, H. Hoshino and K. Taniguchi
Department of Architecture, School of Engineering, The University of Tokyo

ABSTRACT

This study was carried out systematically as follows; at first, an investigation of gross-building-to-land ratio of real residential area with GIS data was carried out. We obtained the result that almost areas locate within the range from 20 to 45%, and the average was 33%. From these results, reproduction-conditions of building-models in the wind tunnel experiment were decided. Secondly, in these reproduction-conditions, wind pressure coefficients of residential buildings were measured. Plan-shapes of target buildings were two kinds. One was rectangular plan with flat roof, gable roof and hipped roof. And the other was L-character-plan with flat roof and gable roof. Analysis of wind pressure coefficients distributions were made according to the density of the urban area and the arrangement of buildings in surrounding. Finally, based on these experimental results, air-flow–network-simulation was carried out, and simplified prediction method of air change rate by cross-ventilation was examined. As a result, simple equation of which variable were opening-Area and external wind velocity for rough prediction of air change rate by cross-ventilation was obtained.

1. INTRODUCTION

In a quantitative evaluation of cross-ventilation, wind pressure coefficients become indispensable. Shoda et al. (1956) examined with rectangular building models changing the surrounding building conditions by the wind tunnel experiment. Nishizawa et al. (2005) examined the cross-ventilation characteristics of detached house based on wind pressure coefficients obtained from the wind tunnel experiment. There are alternative researches on wind pressure coefficients, but, building shapes and surrounding conditions are limited. Therefore, the basic data for the cross-ventilation design seems to be not enough. In this study, “investigation of the density of urban area”, “wind tunnel experiment” and “air-flow-network-simulation” was systematically carried out for the purpose of maintenance the basic data for cross-ventilation design.

2. INVESTIGATION OF THE DENSITY OF ACTUAL URBAN AREA

We investigated the ratio of gross architectural area to the urban area in Tokyo from the GIS data. Hereafter, the ratio is described as gross-building-to-land ratio (R_g).

Figure 1 shows the frequency distribution and cumulative frequency of the ratio of Setagaya Ward and Suginami Ward. Both

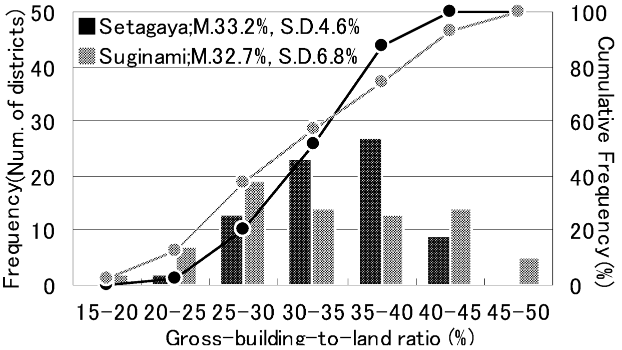


Figure 1: Density of urban area in Setagaya Ward and Suginami Ward.

districts were about 33% to the average, and standard deviation was 4.6% in Setagaya Ward and 6.8% in Suginami Ward.

3. WIND PRESSURE COEFFICIENTS OF RESIDENTIAL BUILDING BASED ON WIND TUNNEL EXPERIMENT

3.1 Outline of Experiment

The experiments were carried out in the wind simulation tunnel at the University of Tokyo (1990). Figure 2 shows the approaching flow profile. Mean wind velocity at the eaves height (H=59mm) was 7 m/s, and the power law exponent was set 0.2 as urban area based on the Recommendation for Load on Buildings (AIJ(1993)).

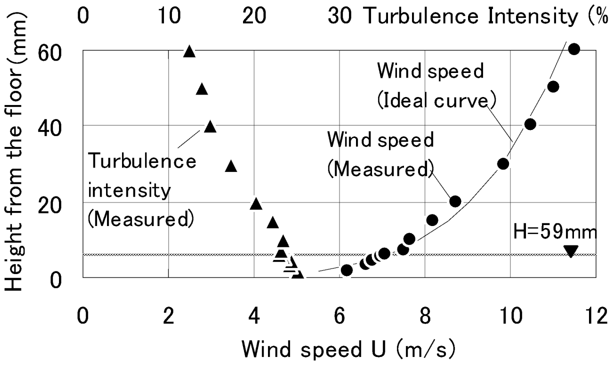


Figure 2: Approaching flow profile.

As shown in Figure 3, plan-shapes of target building models were two kinds. One was rectangular plan with flat roof, gable roof and hipped roof. And the other was L-character plan with flat roof and gable roof. Each models had 153 to 190 wind pressure measurement points on wall and roof surfaces.

As shown in Figure 4, three kinds of the arrangement of surrounding buildings were set as follows; "uniform distribution (case-0)", "target models were located at the center of the block (case-1)" and "located at the corner of the block (case-2)" with R_g=23% to 43% at interval of 5% based on the investigation result of the urban-area-density. Table 1 shows the distance between buildings of each condition of R_g.

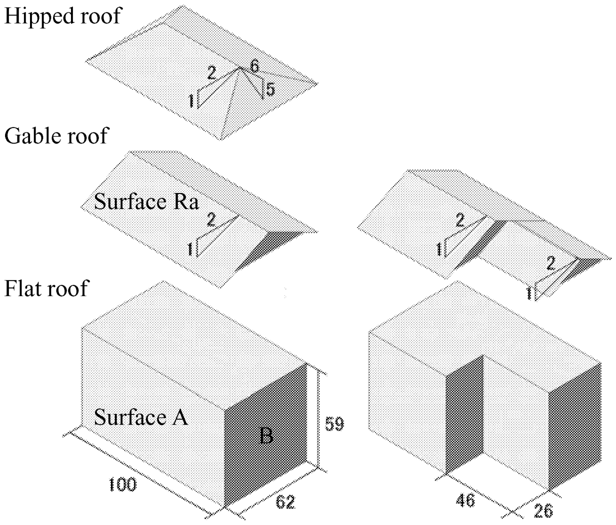


Figure 3: Outline of target models (scale:1/100).
(Left: Rectangular plan, Right: L-character plan)

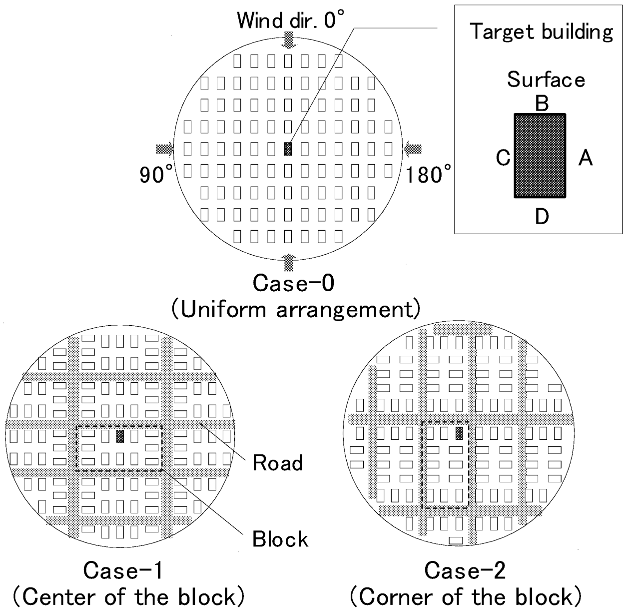
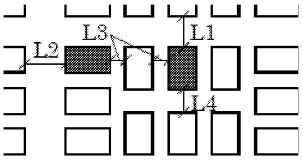


Figure 4: Arrangement of surrounding buildings.

Table 1: Distance between buildings.

R_g (%)	Case-0	Case-1, Case-2			
		L1	L2	L3	L4
23	1.4H	-	-	-	-
28	1.2H	1.5H	1.8H	0.8H	1.4H
33	1.0H	1.4H	1.7H	0.7H	1.0H
38	0.8H	1.2H	1.5H	0.5H	0.7H
43	0.7H	-	-	-	-



3.2 The Relation between the gross-building-to-land ratio and wind pressure coefficients

Hereafter, we discuss on wind pressure coefficients of rectangular-plan-models. Figure 5 shows the correlation of wind pressure coefficients based on R_g=33% in the condition that buildings were arranged uniformly (case-0) and wind direction was 45°. It found that the absolute value of wind pressure coefficients became small according to the increase of R_g from the slope value of the linear regression line. However, slope values of 38% and 43% were almost same. As for the other wind directions, this result was similar as shown in Table 2.

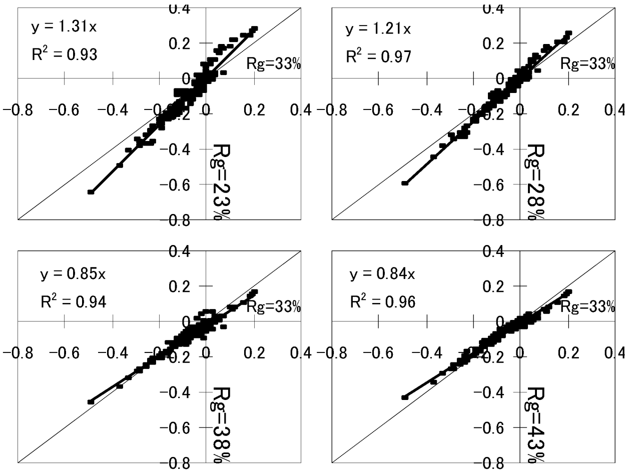


Figure 5: Correlation of wind pressure coefficients based on Rg=33% (Case-0, Wind direction 45°).

Table 2: Slope of linear regression line and R2.

Wind direction	R_g = 23%		R_g = 28%	
	Slope	R2	Slope	R2
0°	1.52	0.91	1.18	0.93
22.5°	1.33	0.93	1.07	0.98
45°	1.36	0.94	1.22	0.97
67.5°	1.03	0.94	1.00	0.99
90°	1.19	0.95	1.05	0.98

Wind direction	R_g = 38%		R_g = 43%	
	Slope	R2	Slope	R2
0°	0.74	0.84	0.63	0.80
22.5°	0.77	0.93	0.72	0.94
45°	0.85	0.94	0.84	0.96
67.5°	0.82	0.96	0.88	0.96
90°	0.95	0.97	0.90	0.97

3.3 The Relation between the arrangement of surrounding buildings and wind pressure coefficients

Figure 6 shows the comparison of mean value of wind pressure coefficient in each surface according to buildings arrangement in R_g=33%. About wall A within wind direction 247.5° to 337.5°, it became positive values in case-2 whose front side was a road, and it became negative values whose front side was the next building. About other surfaces, remarkable differences were not seen.

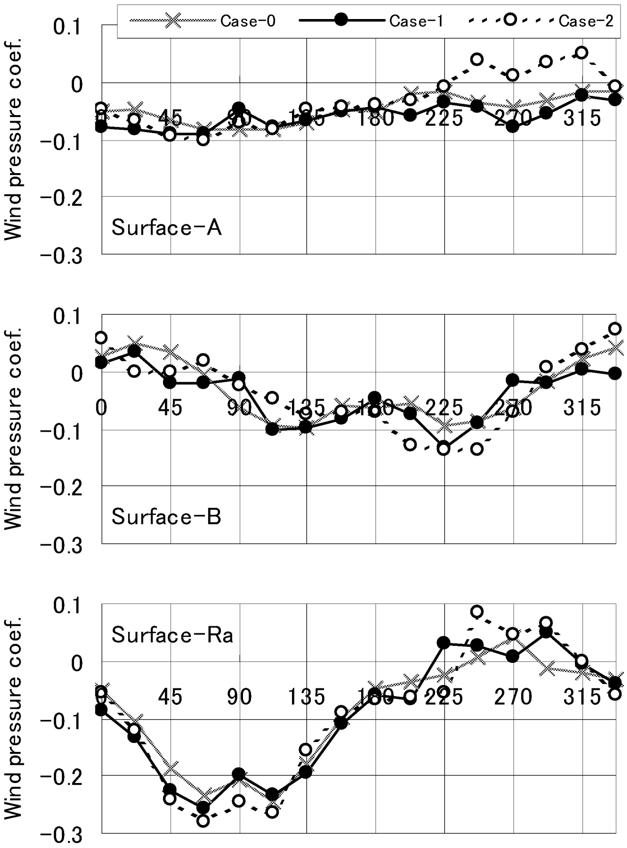


Figure 6: Comparison of mean value of wind pressure coefficient in each surface (Rg=33%).

4. SIMPLIFIED PREDICTION OF AIR CHANGE RATE BY CROSS-VENTILATION

4.1 Outline of Air-Flow-Network-Simulation

Air-Flow-Network-Simulation was carried out based on the result of the wind tunnel experiment. Table 3 shows the outline of the simulation. We use application software VentSim ver3 developed in Building Research

Institute of Japan. Weather data was standard expanded AMeDAS weather data of Tokyo, and the calculation period was from May to October when cross-ventilation can be used mainly in Japan. Figure 7 shows the wind rose and the mean wind velocity in calculation period.

Figure 8 shows outline of target building. It was rectangular plan with gable roof, and was identical with that of the wind tunnel experiment. Rooms of evaluation were LD, Japanese Room (JR), bed room 1 (BR1), and bed room 2 (BR2). Figure 9 shows the arrangement of the target building with the azimuth.

Table 3: Outline of air-flow-network-simulation

Weather data	Standard EA weather data (Tokyo)
Cal. Period	From May to October
Windows	Always opened (Cd=0.65)
Partition doors	Always closed
Stack Vent.	Not considered

Calculation cases of surrounding buildings arrangement

Cases	Rg				
	23%	28%	33%	38%	43%
Case-0	○	○	○	○	○
Case-1	—	○	○	○	—
Case-2	—	○	○	○	—

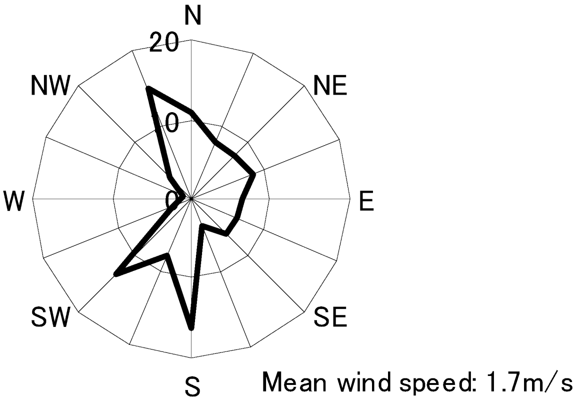


Figure 7: Wind rose and mean wind velocity in Tokyo (from May to October)

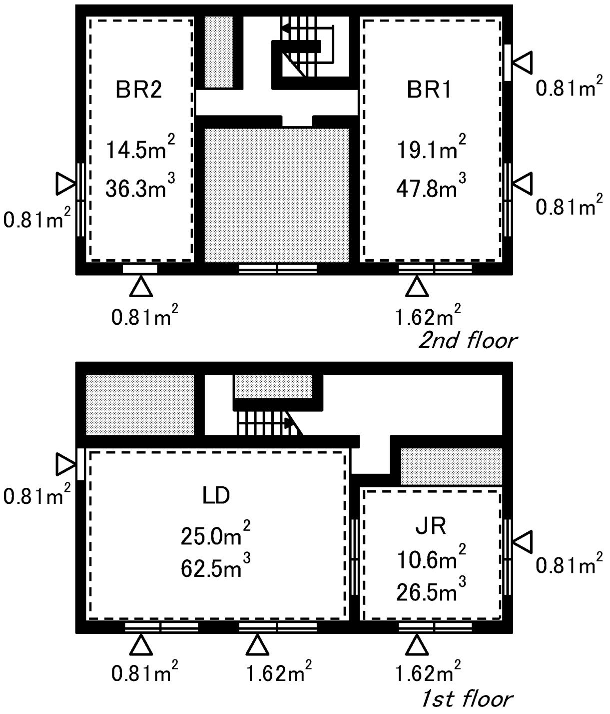


Figure 8: Outline of target building.

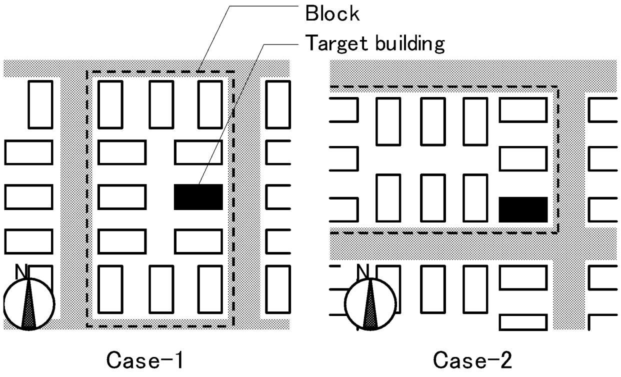


Figure 9: Arrangement of target building and azimuth

4.2 Wind Pressure Coefficient Differences

Mean values of wind pressure coefficient differences among openings of each room are shown in Figure 10. These values were calculated in weighted averaging of the frequency wind direction. As shown in this figure, it was found that as the value of R_b increase, they decrease. There was not remarkable difference among the case-0 and the case-1. But the value of case-2 was about 30% higher than case-0 and case-1.

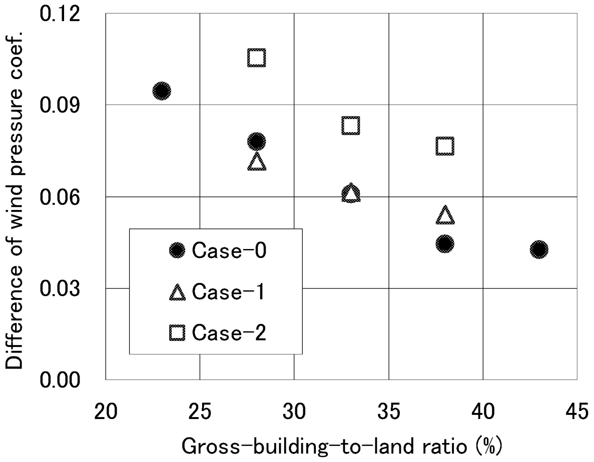


Figure 10: Mean values of wind pressure coefficient differences among openings of each room.

4.3 Air Change Rate by Cross-Ventilation according to the Wind Velocity

Figure 11 shows the daily mean value of air change rate by cross-ventilation and outer wind velocity (V) in August. These daily fluctuation have same tendency. Figure 12 shows the relation of hourly outer wind velocity and air change rate in each case. From this figure, although there were some errors originated from the wind direction, it could be suggested that air change rate might be estimated roughly from an external wind velocity.

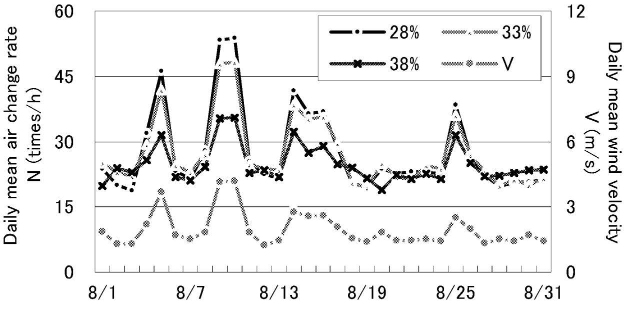


Figure 11: Daily mean value of air change rate by cross-ventilation and outer wind velocity in August.

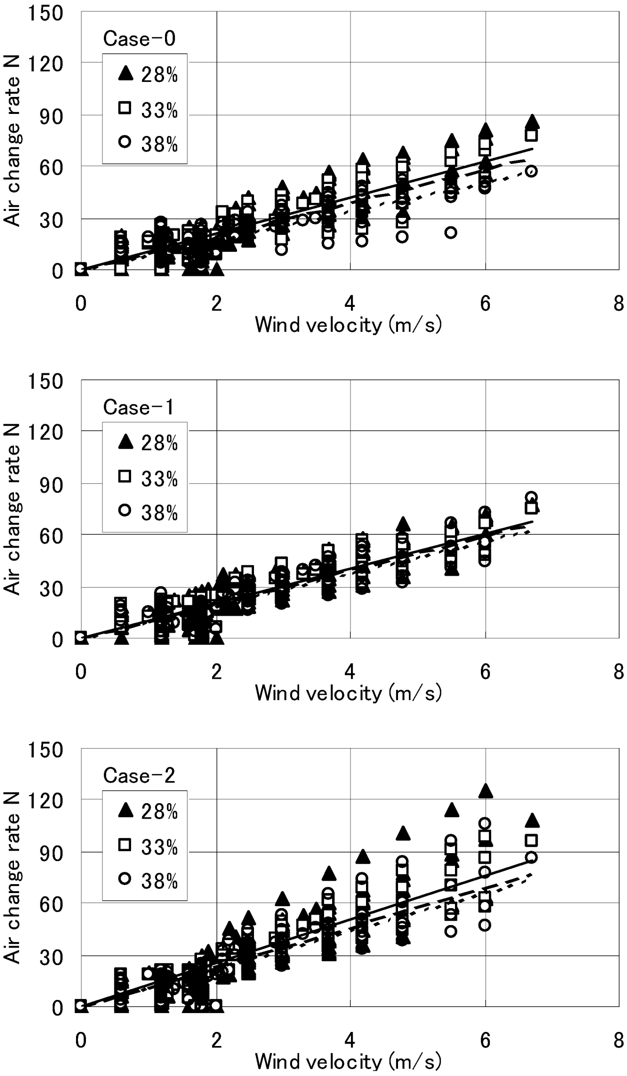


Figure 12: Relation of hourly outer wind velocity and air change rate in each case.

Here, we defined the effective opening ratio R_{Aw} which was the ratio of total effective opening area and floor area in each room as shown in equation (1).

$$R_{Aw} = \frac{\overline{C_d A_w}}{A_f} \qquad (1)$$

where:

R_{Aw} : Effective opening ratio (dimensionless)

C_d : Discharge coefficient (dimensionless)

A_w : Opening area (m^2)

$\overline{C_d A_w}$: Total effective opening area (m^2)

A_f : Floor area of the room (m^2)

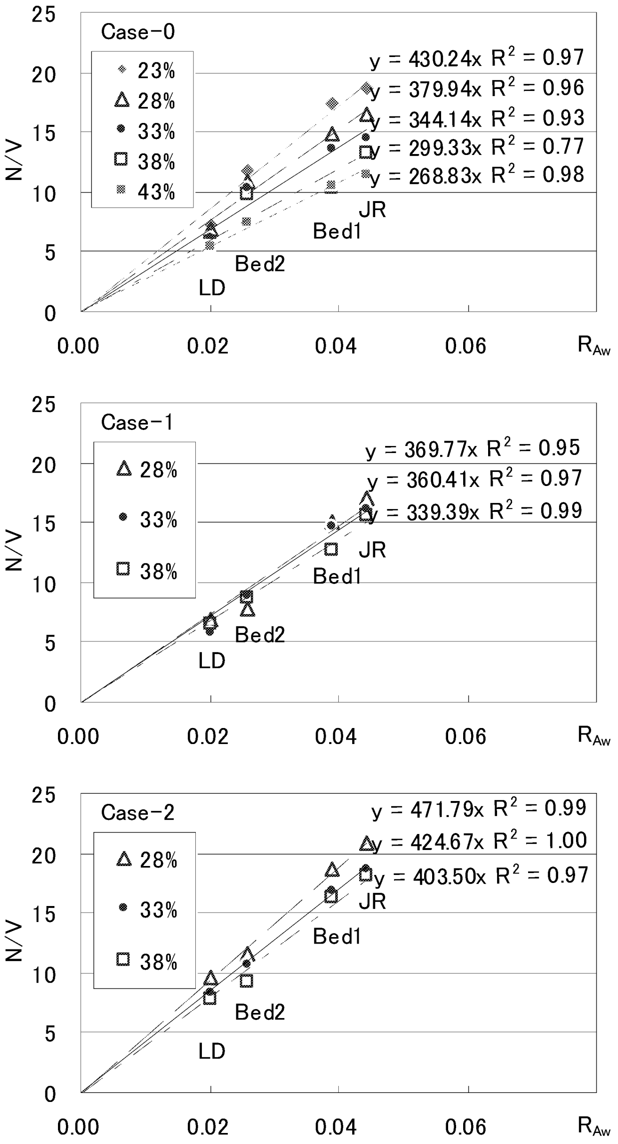


Figure 13: Relation of R_{Aw} and the ratio N/V.

Figure 13 shows the relation of R_{Aw} and the ratio N/V where N is air change rate (times/h) by cross-ventilation and V is outer wind velocity (m/s). As shown in this figure, there are high correlations in R_{Aw} and N/V in each case. From this result, we proposed an equation (2) which could estimate air change rate by cross-ventilation roughly by outer wind velocity.

$$N = CR_{Aw} \times V \qquad (2)$$

where:

N : Air change rate by cross-ventilation (times/h)

V : Outer wind velocity (m/s)

C : Constant value

"C" is a constant value decided by surrounding building conditions and weather data. Table 4 shows values of "C" in Tokyo calculated in this study. If this parameter of various places is maintained, designers can roughly but simply estimate air change rate from weather data according to the surrounding building conditions.

Table 4: Values of "C" in Tokyo

Rg	Case -0	Case-1	Case-2
23%	430.2	—	—
28%	379.4	369.7	471.9
33%	344.1	360.4	424.7
38%	299.3	339.4	403.5
43%	268.8	—	—

5. CONCLUSION

Wind pressure coefficient of various building models were obtained by the wind tunnel experiment where surrounding buildings arrangement were based on the investigation of the density of real urban area.

Based on the wind tunnel results, air-flow-network-simulation was carried out. And simple equation for estimating air change rate by cross-ventilation roughly was proposed.

ACKNOWLEDGEMENT

This work was supported by Grant-in-Aid for Scientific Research (B) (19360256) from Japan Society for the Promotion of Science (JSPS).

REFERENCES

Shoda, T. and Gotoh S., 1956. Effects of Exposure on Ventilation of Buildings, Transactions of AIJ, No. 53, pp. 80-87 (in Japanese)

Nishizawa, S., Sawachi, T., Maruta, E., Seto, H. and Kurabuchi, T., 2005. Wind Pressure Coefficient on Detached Houses in the Densely Built-up Area, Summaries of Technical Papers of Annual Meeting AIJ, D-2, pp. 795-796 (in Japanese)

Itoi, T., Kurita, T., Imano, M., Kamata, M. and Kanda, J., 1999, Wind Simulation Tunnel at Department of Architecture, University of Tokyo, J. of Wind Engineering, No. 81, pp. 1-7 (in Japanese)

AIJ, 1993. Recommendations for Loads on Buildings, AIJ (in Japanese)