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A WIND TUNNEL EXPERIMENT OF WIND FORCED NATURAL VENTILATION OF A DETACHED HOUSE

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ABSTRACT

Wind-induced natural ventilation of a city house is strongly influenced by the adjoining buildings. In this paper, a wind tunnel experiment using a one storey model house has been carried out to clarify the influence of surroundings on the distribution of the wind pressure coefficients Cp around the house. In addition, the natural ventilation rate is calculated using a method which considers the distribution of Cp and leakage area around the house. The effect of surroundings on the natural ventilation has been studied by changing the density of surrounding buildings, i.e. building coverage, K. The results are as follows;

(1) The coefficient Cp of the windward wall changes greatly according to the wind direction.
(2) In the case of building coverage K changing from 0 to 40% regardless of the wind direction, the air change rate decreases to about 40%-50% compared to the case of K=0.
(3) An air change rate is 0.8 1/h when in a leakage area of 12.5cm^2/m^2, southern wind direction , a wind velocity of 4m/s, a building coverage of 20% and leakage area coefficient n=2.
(4) The air change rate for the house is dependent on the value of the coefficient n which is determined by the character of the leakage area when a wind velocity is greater than 3m/s.

KEYWORDS

Natural ventilation, Air change rate, Wind tunnel experiment, Wind pressure coefficient, Air tightness, Building coverage, Detached house

INTRODUCTION

Wind-induced natural ventilation of a city house is strongly influenced by the adjoining buildings. For example, Shoda et.al. have reported wind tunnel experiment of the change in the wind pressure coefficient when a building is obstructed. In these papers, wind-induced natural ventilation was calculated from the difference of the windward pressure coefficient and leeward pressure coefficient. There are few examples where the distribution of the wind pressure coefficient is being taken into consideration. It is important to clarify the detailed influence of surroundings and shapes of the house on natural ventilation for energy saving and the indoor environment control for air tight and highly insulated house.

In this paper, particular attention is paid to the followings;

(1) The detailed distribution of the wind pressure coefficient on the wall and the roof.

(2) A wind tunnel experiment has been carried out considering to the influence analysis of surroundings and the distribution of the wind pressure coefficient around the house.

(3) The natural ventilation rate is calculated using a method which considers the distribution of the wind pressure coefficient and leakage area around the house.

Symbols

U : Mean wind velocity (m/s)
U_H: Mean wind velocity at the height of H (m/s)
H : Height of the model roof (mm)
C : Wind pressure coefficient
θ : Wind direction (°)
K : Building coverage rate (%)
N : Air change rate (1/h)
Q : Air flow rate (m³/h)
Qo : Air flow rate in the case of K=0%, θ=0°
n : Coefficient of the leakage area character

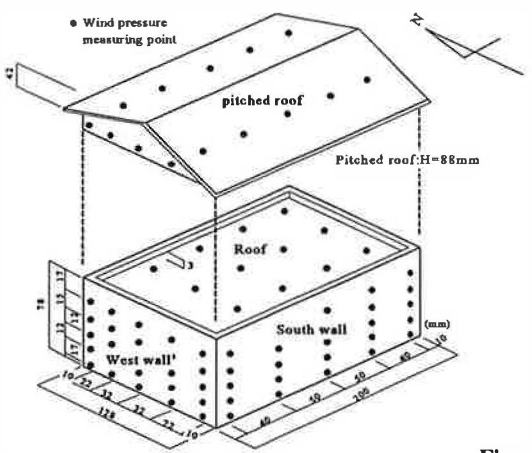


Figure 1. Model of the house and wind pressure measuring points

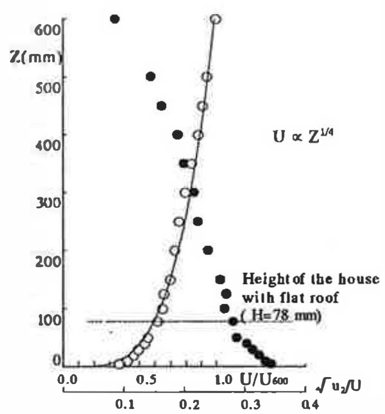


Figure 2. Velocity profile and turbulence intensity of the approaching wind

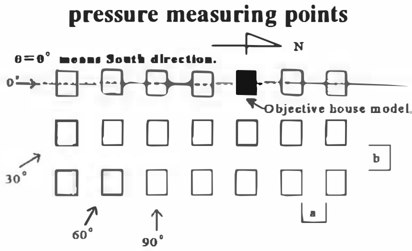


Figure 3. The arrangement of the house and a wind direction

Table 1. Experimental Conditions for K and θ

	K(%)	θ (°)
flat roof	0	0, 30, 60, 90
	5	0, 30, 60, 90
	20	0, 30, 60, 90
	40	0, 30, 60, 90
pitched roof	0	0, 30, 60, 90
	5	0, 30, 60, 90
	20	0

K: Building coverage θ: Wind direction

(4) The influence of surrounding buildings on the wind pressure.
(5) The relationship between air tightness and the air change rate.

OUTLINE OF EXPERIMENTS

Model of house

Figure 1 shows a model of a house which has a width of 10m, a depth of 6.4m and there are six rooms in this house. Two types of roof have been examined a flat roof and a pitched roof. The height of the house with a flat roof is 3.9m and that for the pitched roof is 4.4m. A 1/50 scale model has been used for this wind tunnel experiment. The wind pressure measuring points for the flat roof is 15 points and the pitched roof are 10 points. 25 pressure measuring points are used on each wall of the model.

Wind tunnel and boundary layer

A boundary layer type wind tunnel of I.I.S. University of Tokyo has been used for the pressure measurement. A boundary layer of $U \propto Z^{1/4}$ (figure 2) was formed by rectangular fences and artificial grass.

Experimental conditions

Two kinds of experimental models with different roof types were examined. The wind directions were θ=0°, 30°, 60°, 90°. Surrounding buildings were the same as the testing model house. The arrangement of the parameters (the models and wind directions) are shown in the figure 3. The building coverage rate K changes from 0 to 40% (Table 1), and the building coverage rate K = 0% means an isolated house without surroundings.

Method of measuring of the wind pressure coefficient

The reference static pressure was measured at a windward point from the model at mid height of the wind tunnel, where the pressure was not affected by the installed model and almost same as the static pressure at the height of the model when the model was not installed. The wind pressure coefficient on the surface of the model was all normalized with respect to the dynamic pressure at the height of the model. The reference height in case of the flat roof was 78 mm, and in case of pitched roof it was 88 mm.

Method of calculating the ventilation rate

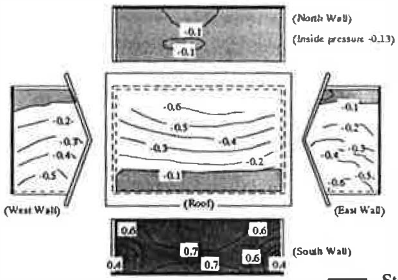
It is necessary to assume the distribution of the leakage area and indoor pressure to predict the ventilation rate based on the wind pressure distribution obtained from the wind tunnel experiment. In this study, considering that the model houses have single interior zone including roof-space and floor-space, it is assumed that the total leakage area of the building is proportionally divided to the representative area of the wind pressure measurement point on the walls or the roofs. The internal pressure is approximately calculated by the iteration method. A ventilation rate is calculated from the pressure difference between the external and internal walls and roof surfaces.

(2) The effects of K (θ=0°)

The value of C in the center of the windward south wall decreases as K increases(Figure 9). The value of C is 0.4 even for K=20% compared to 0.2 in the case of the flat roof. The value of C at the center of the south side of the roof has a constant value of about -0.1 for different values of K.

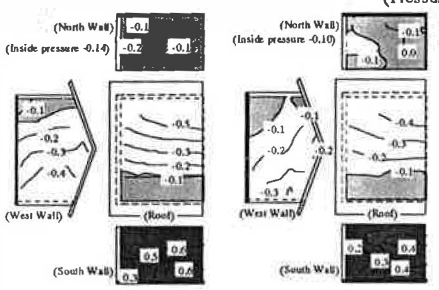
The wind pressure distribution of the wall and the roof, and the results of the ex-infiltration field

Figure 10 shows the distribution of C for each wall surface for different values of K in case of θ=0°. The figure also shows the internal pressure, the air infiltration regions (where the pressure difference of internal pressure and each external pressure on the wall becomes +), with K increases. The distribution of the C on the roof for K=0 is similar to that for K=40%. The infiltration field is in the windward south and the leeward north walls, and the exfiltration field is in the east and west walls. Figure 10 (1) and Figure 11 show the distribution of the C on each surface and the infiltration fields with θ for K=0. When wind direction θ changes from south to east, the infiltration from the south wall decreases. When θ=90°, exfiltration occurs on south wall. When θ=0°, the north part of the east wall is an infiltration field, and as θ changes from 0° to 90°,



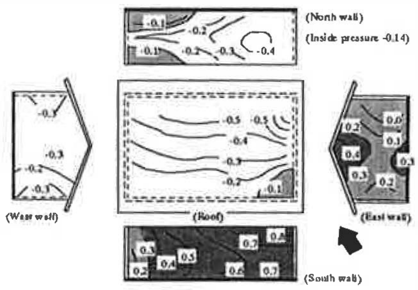
(1) K=0% (θ=0°)

Strong inflow area
(Pressure difference exceed 0.3)
Inflow area
(Pressure difference less than 0.3)

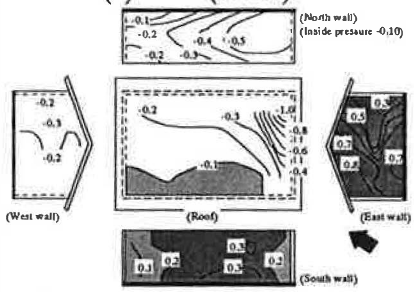


(2) K=5% (θ=0°) (3) K=20% (θ=0°)

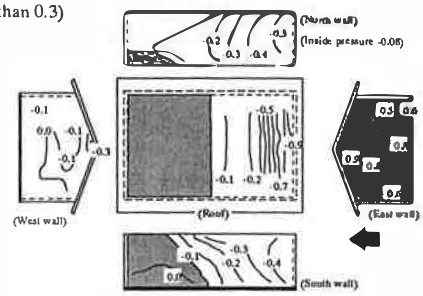
Figure 10. Distribution of the C
(pitched roof. θ=0°, n=2, K=0 to 20%)



(1) θ=30° (K=0%)



(2) θ=60° (K=0%)



(3) θ=90° (K=0%)

Figure 11. Distribution of the C
(pitched roof. K=0%, n=2, θ=30 to 90°)

infiltration field increases. The windward part of the roof becomes infiltration field when the θ=0° - 30°, but when θ=90°, the windward part of the roof becomes exfiltration field.

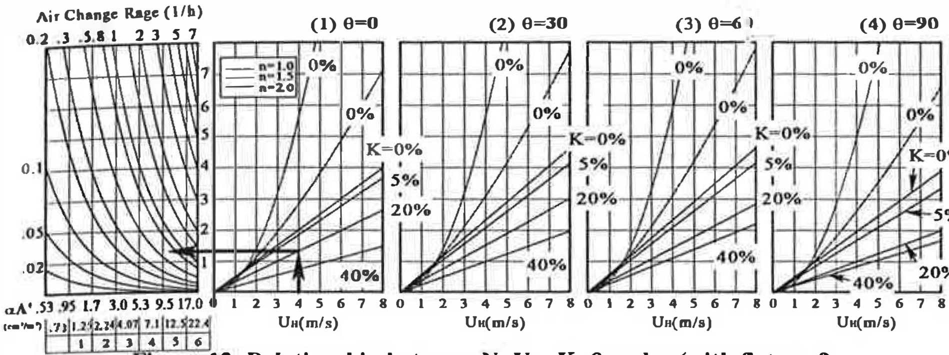


Figure 12. Relationship between N, U_H, K, θ and n (with flat roof)

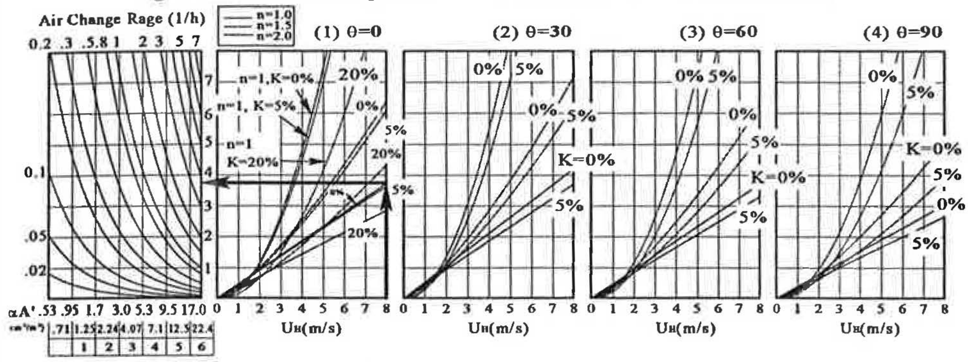


Figure 13. Relationship between N, U_H, K, θ and n (with pitched roof)

Table2. Relationship between N, U_H, K, θ and n (with flat roof)

Roof Type	θ	n	K	N
flat roof	0	1.0	0	$N = 0.0160\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0204\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0228\ V_H \cdot \alpha A$
	30	1.0	0	$N = 0.0161\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0220\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0264\ V_H \cdot \alpha A$
			5	$N = 0.0236\ V_H \cdot \alpha A$
			20	$N = 0.0172\ V_H \cdot \alpha A$
			40	$N = 0.0112\ V_H \cdot \alpha A$
	60	1.0	0	$N = 0.0168\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0224\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0264\ V_H \cdot \alpha A$
			5	$N = 0.0237\ V_H \cdot \alpha A$
			20	$N = 0.0162\ V_H \cdot \alpha A$
			40	$N = 0.0125\ V_H \cdot \alpha A$
	90	1.0	0	$N = 0.0142\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0188\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0222\ V_H \cdot \alpha A$
			5	$N = 0.0190\ V_H \cdot \alpha A$
			20	$N = 0.0113\ V_H \cdot \alpha A$
			40	$N = 0.0095\ V_H \cdot \alpha A$

Table3. Relationship between N, U_H, K, θ and n (with pitched roof)

Roof Type	θ	n	K	N
pitched roof	0	1.0	0	$N = 0.0137\ V_H^2 \cdot \alpha A$
			5	$N = 0.0129\ V_H^2 \cdot \alpha A$
			20	$N = 0.0078\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0183\ V_H^{(1.5/2)} \cdot \alpha A$
			5	$N = 0.0174\ V_H^{(1.5/2)} \cdot \alpha A$
			20	$N = 0.0124\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0212\ V_H \cdot \alpha A$
			5	$N = 0.0207\ V_H \cdot \alpha A$
			20	$N = 0.0163\ V_H \cdot \alpha A$
	30	1.0	0	$N = 0.0156\ V_H^2 \cdot \alpha A$
			5	$N = 0.0130\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0205\ V_H^{(1.5/2)} \cdot \alpha A$
			5	$N = 0.0179\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0240\ V_H \cdot \alpha A$
			5	$N = 0.0212\ V_H \cdot \alpha A$
	60	1.0	0	$N = 0.0134\ V_H^2 \cdot \alpha A$
			5	$N = 0.0104\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0179\ V_H^{(1.5/2)} \cdot \alpha A$
			5	$N = 0.0150\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0212\ V_H \cdot \alpha A$
			5	$N = 0.0188\ V_H \cdot \alpha A$
	90	1.0	0	$N = 0.0109\ V_H^2 \cdot \alpha A$
			5	$N = 0.0076\ V_H^2 \cdot \alpha A$
		1.5	0	$N = 0.0145\ V_H^{(1.5/2)} \cdot \alpha A$
			5	$N = 0.0113\ V_H^{(1.5/2)} \cdot \alpha A$
		2.0	0	$N = 0.0174\ V_H \cdot \alpha A$
			5	$N = 0.0152\ V_H \cdot \alpha A$

THE RELATION BETWEEN AIR-TIGHTNESS AND AIR CHANGE RATE

The house with flat roof

Figure 12 and Table2 show the relationship between the air change rate N and the mean wind velocity, building coverage K, wind direction θ and the leakage area coefficient n. The N becomes 0.8 1/h when the grade of air-tightness(Mirakami et al.) is 5th($\alpha A'=12.5cm^2/m^2$), Uh=4m/s, θ=0°, K= 20% and n=2. A change for the n value has a big influence on N when Uh is greater than 3 m/s.

The house with pitched roof

Figure 13 and Table3 show the relationship in the case of the pitched roof. A change for the n value has a big influence on N as the same of Figure12. The value of air change rate is the same as that for the flat roof case of θ=0°, but in the case of θ=90°, the value of N is slightly smaller. In the case of K=0%, n=2, Uh=8m/s, (when the grade of air-tightness is 6^{th} ($\alpha A'=22.4cm^2/m^2$)) N for the flat roof is about 4.0 1/h, and for the pitched roof it is about 3.0 1/h.

CONCLUSION

(1) The wind pressure coefficient C of the windward wall changes greatly when the wind direction changes. The value of C is within the range of 0.1~-0.2 for all side of walls and roof in the case of building coverage K=40%.
(2) In the case of building coverage K=0-20%, the infiltration and exfiltration area are not distinct except for the windward wall. Furthermore, there is exfiltration even in the windward wall for the case of K=40%. When K changes from 0 to 40% regardless of the wind direction, the air change rate decreases to about 40%-50% compared to the case of K=0 for the flat roof.
(3) A chart which shows the relationship between the air change rate and air-tightness, outdoor wind direction and velocity, building coverage rate and the character of leakage area has been constructed from the distribution of the assumed leakage area and measured distribution of wind pressure coefficient for a detached house.
(4) From the chart in (3) the air change rate for flat roof house of 0.8 1/h was obtained for an air-tightness grade of a 5th, a wind direction of 0°, a wind velocity of 4m/s, a building coverage rate of 20% and leakage area character of 2.
(5) The air change rate for all the houses in this experiment is dependent on the value of the coefficient n which indicates the character of the leakage area when a wind velocity beyond 3m/s.

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