# Study on Airflow around Building Roof for Design of Natural Ventilation by Chimney
# -Part2 Wind Velocity Distribution above Building Roof-

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## ABSTRACT

The purpose of this study is to clarify the characteristics of airflow around building roof and to provide the guidelines for design of natural ventilation by chimney. Previous part of this paper showed the distribution of wind pressure coefficient on flat rooftop of buildings obtained from the wind tunnel test to find the proper position of a chimney on building roof. This part of the paper shows the wind velocity distribution above building roof to find the proper height of a chimney and to analyze the characteristics of separated flow above building roof.

Wind tunnel test was carried out with two different models. The height was 200mm and the dimension of the rooftop was 100mm×100mm and 100mm×200mm. Measurement points are located at 5 to 50mm above from the surface of building roof. Boundary layer was made in the wind tunnel. Wind direction was changed as 0°, 22.5°, 45° and 90°. Wind velocities above the building roof were measured with hot-wire anemometer. Based on the experimental data, the better position and height of chimneys on building roof are presumed depending on the aspect ratio of the building and wind direction.

As a result, some tendencies were obtained. From the viewpoint of geometry of each model, separation of airflow mainly depends on the windward wall area. In contrast, the depth of the model has less effect. In addition, in case of windward side of rooftop, chimney height can be lowered.

## 1. INTRODUCTION

Recently natural ventilation has been receiving increasing attention for saving energy and utilization of natural energy and various studies have been conducted on natural ventilation. Conventionally, Ishihara (1969) has shown the study on monitor roof and roof ventilator as a supplementary equipment of natural ventilation, and recently some researchers has shown the study on the natural ventilation by solar chimney (Cho et al (2000), Shinada et al (2005), Maesaka et al (2007), and so on). Komatsu et al. (2007) showed the study on natural ventilation for the specific school building with wind chimneys on building roof, located in the west part of Japan. The natural ventilation system uses wind driving force of negative pressure on the rooftop of wind chimneys and buoyancy force caused by the heat generation by occupants in lecture rooms.

The goal of this study is to provide the guidelines for natural ventilation design by chimney for common buildings, therefore, authors carried out wind tunnel test with the building model of simple aspect ratios. This paper reports the results of visualization and wind velocity measurement to clarify characteristics of airflow around building roofs.

## 2. VISUALIZATION EXPERIMENT

### *2.1 Experimental Procedure*

Wind tunnel test was carried out at Osaka University. Turbulent boundary layer following

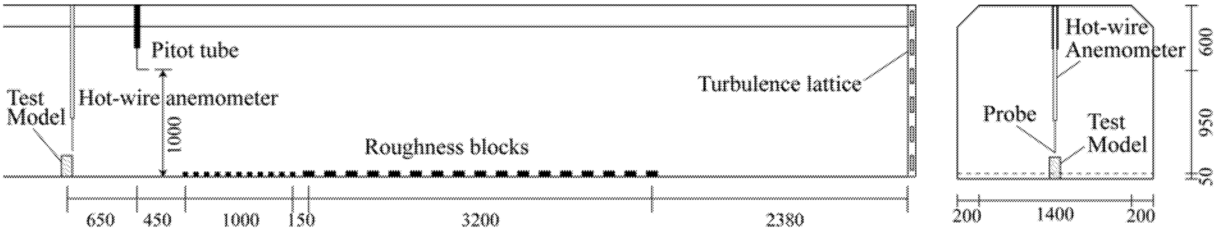


Figure 1. Section of wind tunnel

Table 1. Geometry of test models

| | Model Name | |
|---|---|---|
| | 1M | 2M |
| Roof plan (mm) | 100×100 | 100×200 |
| Height (mm) | 200 | 200 |

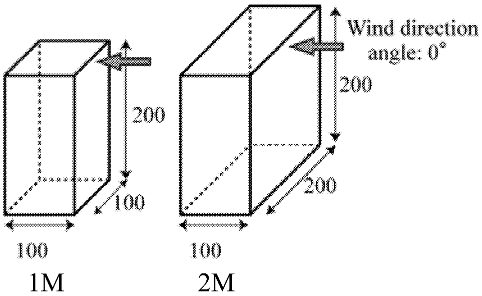


Figure 2. Geometry of test models (unit is mm)

1/4.5 power rule with the velocity of 2 m/s at the outer edge of the boundary layer was made in wind tunnel and experimental building models are placed on the floor of wind tunnel, as shown in Figure 1.

Table 1 and Figure 2 show experimental building models. Each model has simple aspect ratio. Smoke wire method is applied for visualization experiment, using nichrome wire with liquid paraffin and lazer (YAG lazer, CW-532-600M, KANOMAX).

*2.2 Results and Discussions*

Airflow around building roof of Model-1M, wind direction angle of 0° and 45° are shown in Figure 3 and Figure 4. It is clear from two figures that the height of separation zone of wind direction angle of 45° is much smaller than that of wind direction angle of 0°. Figure 5 shows airflow around building roof of Model-2M, wind direction angle of 0°. It appears that there is a possibility of flow reattachment.

The results of Model-1M, wind direction angle of 0° and Model-2M, wind direction angle of 90° show characteristic tendencies, as shown in Figure 3 and Figure 6. From the viewpoint of

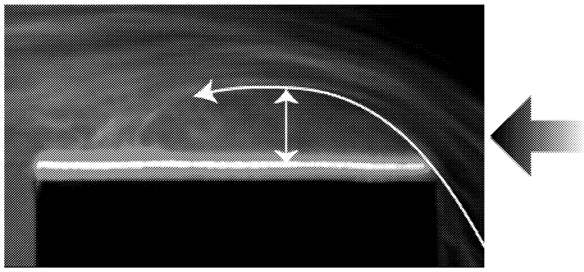

Figure 3. Flow above the rooftop of Model-1M, Wind direction angle of 0°

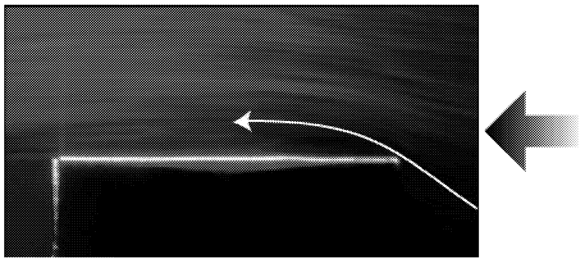

Figure 4. Flow above the rooftop of Model-1M, Wind direction angle of 45°

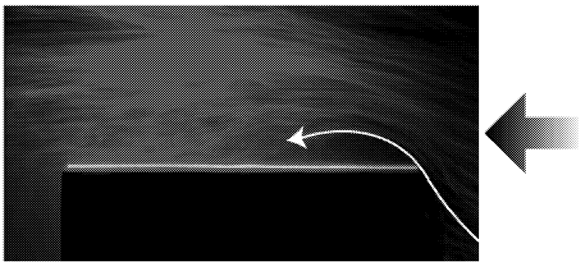

Figure 5. Flow above the rooftop of Model-2M, Wind direction angle of 0°

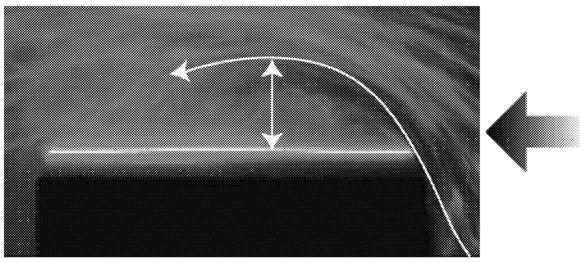

Figure 6. Flow above the rooftop of Model-2M, Wind direction angle of 90°

geometry of two models, both have the same heights, but the area of the rooftop and windward area of Model-2M is two times as large as the one of Model-1M. From these two pictures, it is shown that the height of separation zone of Model-2M is taller than Model-1. The reason of this difference seems that the windward wall area of Model-2M has double. Therefore, in the case of Model-2M, it appears that upward airflow around the model façade is more dominant than that of Model-1M.

The results from visualization experiment indicate that chimney height can be lowered in the case of dominant wind direction angle of 45° to improve natural ventilation performance and windward façade wall areas of buildings have a close relation to airflow characteristics around building roofs.

## 3. WIND VELOCITY MEASUREMENT

### *3.1 Method*

Turbulent boundary layer following 1/4.5 power rule with the velocity of 10 m/s at the outer edge of the boundary layer was made in wind tunnel, as shown in the previous part of this paper (Watanabe et al. 2008). In this part of the paper, we report the results of wind velocity measurement on Model-1M and Model-2M because these two models are more likely to be existent buildings.

The probe of hot-wire anemometer is single wire for one velocity component (SYSTEM712, φ0.5μm tungsten, KANOMAX). The average values of velocity during 30 seconds were calculated from the data obtained with the sampling frequency of 500Hz. Hot-wire probe is placed perpendicular to wind direction in wind tunnel. Firstly, Hot-wire anemometer is positioned at the height of 5mm above the rooftop and moved upward by using a three-dimensional traverser until the turbulent intensity of wind velocity becomes small.

### *3.2 Experimental Conditions*

Experimental conditions are shown in Table 2. Based on the results of visualization experiment, wind velocity is measured from 5mm to 50mm above the building rooftop. Measurement points basically correspond to that of wind pressure measurement.

Measurement points are closely-spaced at the windward edge of building rooftop because the variation of wind velocity is considered to be large as wind pressure. In addition, measurement points are varied with wind direction as wind pressure measurement. For example, whole points are measured at 22.5°. Half points are measured at 0°, 45°, 90° using symmetry geometry of building rooftop.

Table 2. Conditions of Wind Velocity Measurement

| Model | Wind direction angle [°] | Height of Measurement points [mm] |
|---|---|---|
| 1M | 0 | 5, 10, 15, 20, 30, 40 |
| | 22.5 | 5, 10, 15, 20, 30 |
| | 45 | 5, 10, 15, 20 |
| 2M | 0 | 5, 10, 15, 20, 30, 40 |
| | 90 | 5, 10, 15, 20, 30, 50 |

### *3.3 Distribution of Mean Wind Velocity*

Figure 7 shows the distribution of mean wind velocity in the case of Model-1M, wind

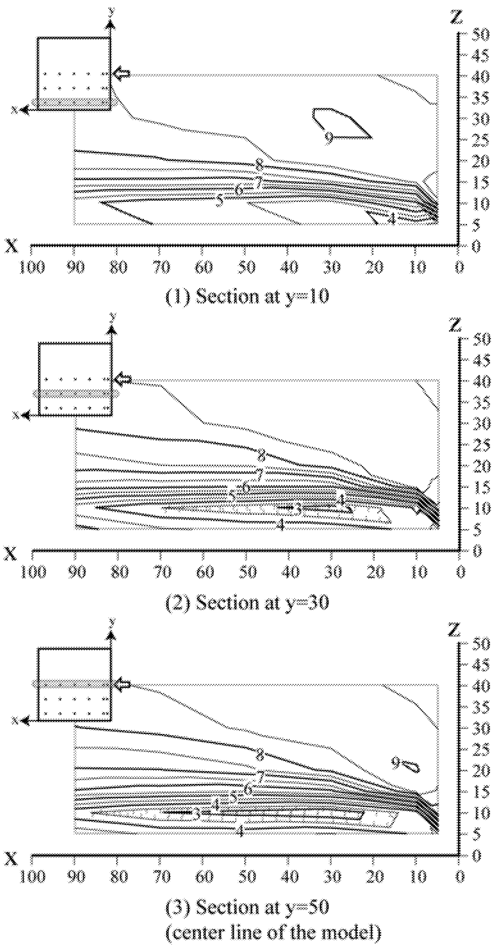


Figure 7. Wind velocity distribution of Model-1M, Wind direction angle: 0° ［m/s］

direction angle of 0°. The distribution is shown in x-z section and the right side is windward. The figure shows the results of y=10, y=30, y=50(mm). From these figures, distribution range of mean wind velocity is approximately from 3 m/s to 9 m/s. It can be seen that mean velocity distribution at y=50 shows larger separation zone than the other conditions. In other words, the value of wind velocity above central axis of each model has the minimum value at the same x-axis. In addition, one characteristic of separation is that the value of wind velocity in separation zone is over 3 m/s, which is larger than expected.

Figure 8 shows the distribution of mean wind velocity in the case of Model-2M, wind direction angle of 0°. The distribution is shown in x-z section and the right side is windward. From the point of view of geometry, windward wall area is equal to Model-1M at the wind direction angle of 0°, but the depth is double. Compared with Figure 7 in the range of x≤100, mean wind velocity value is not so apart from the value in Figure 8.

Figure 9 shows the distribution of mean wind velocity in the case of Model-2M, wind direction angle of 90°. Average wind distribution is shown in y-z section and the right side is windward. Compared with Model-1M at the wind direction angle of 0° from the viewpoint of geometry, depth is equal but windward wall area is double. It is clear that separation zone is larger than Model-1M, in the case of wind direction angle of 0°.

Therefore, the larger windward wall area is, the larger separation zone becomes in the case of models whose heights are equal.

The results from wind velocity measurement on the basis of visualization experiment indicate that windward wall area of building has an apparent effect on the airflow characteristics around building roofs. In addition, for improving natural ventilation performance, chimney height should be tall as possible. In case of windward side of rooftop, chimney height can be lowered.

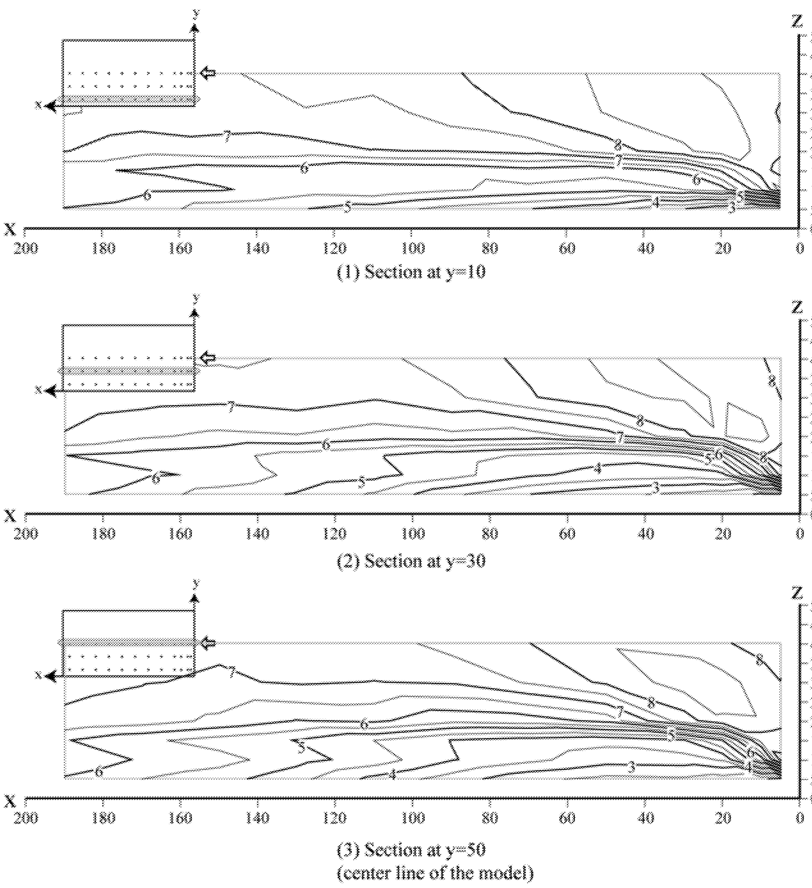


Figure 8. Wind velocity distribution of Model-2M, Wind direction angle: 0° ［m/s］

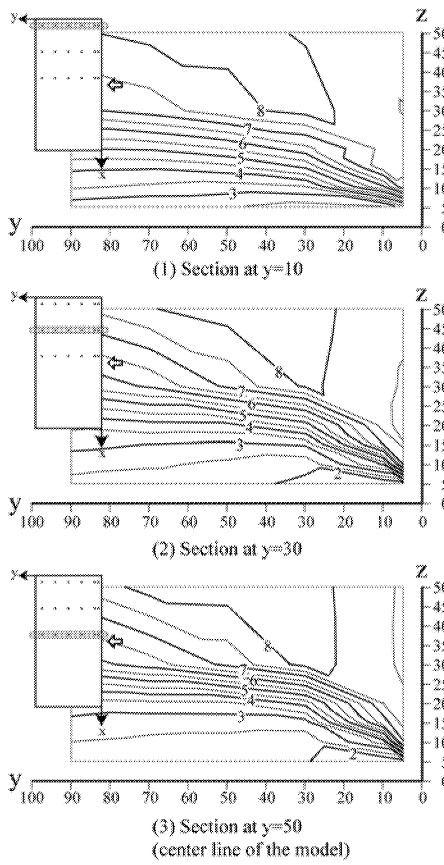


Figure 9. Wind velocity distribution of Model-2M, Wind direction angle: 90° ［m/s］

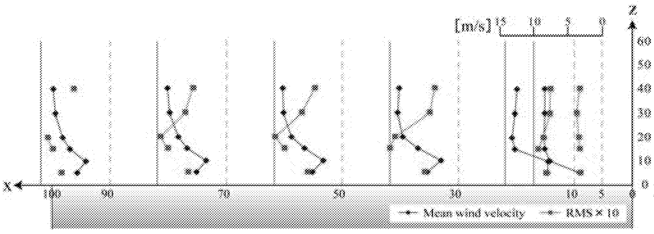


Figure 10. Vertical distribution of mean wind velocity and RMS of wind velocity at y=50, wind direction angle of 0°, Model-1M

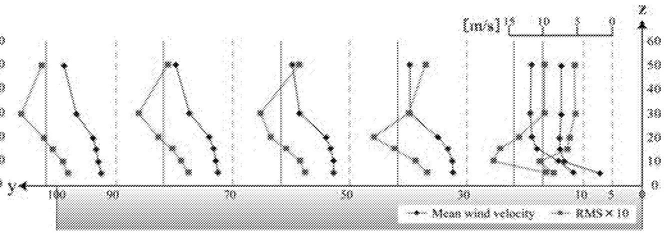


Figure 11. Vertical distribution of mean wind velocity and RMS of wind velocity at x=90, wind direction angle of 90°, Model-2M

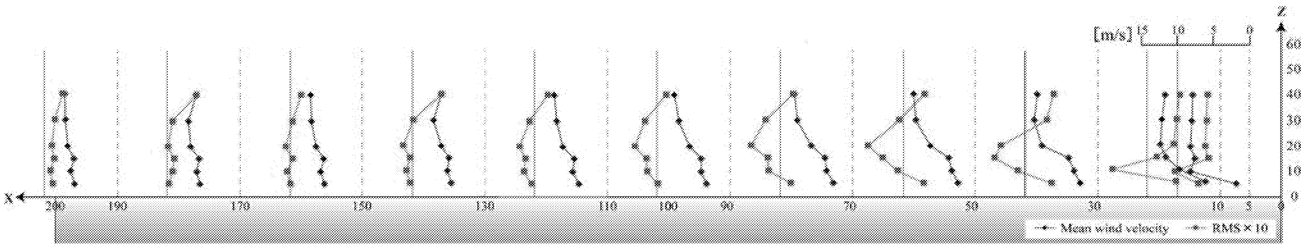


Figure 12. Vertical distribution of mean wind velocity and RMS of wind velocity at y=50, wind direction angle of 0°, Model-2M

*3.4 Vertical Distribution of Mean Wind Velocity and RMS of Turbulent Component*

Figure 10 shows x-z sectional vertical distribution of mean wind velocity and Root Mean Square (RMS) value of wind velocity at y=50 (center line of the model), wind direction angle of 0° in the case of Model-1M. The right side is windward. RMS of wind velocity shown in the figure is ten times of the real value of RMS of turbulent component. Measured points are located at x=5, 10, 30, 50, 70, 90.

Similarly, Figure 11 shows y-z sectional vertical distribution of mean wind velocity and RMS value of wind velocity at x=90 (center line of the model), wind direction angle of 90° in the case of Model-2M. Measured points are located at y=5, 10, 30, 50, 70, 90.

Figure 12 shows x-z sectional vertical distribution of mean wind velocity and RMS value of wind velocity at y=50 (center line of the model), wind direction angle of 0° in the case of Model-2M. Measured points are located at x=5, 10, 30, 50, 70, 90, 110, 130, 150, 170, 190.

In the case of Model-1M, wind direction angle of 0° shown in Figure 10, RMS value is maximum at z=15 near the windward separation point (y≤10). Then RMS value is maximum at z=30 on the leeward side (x≥50). Mean wind velocity is approximately 7 m/s at the height of maximum RMS value of wind velocity. The height of separation zone is considered to be located immediately above the height of maximum RMS value. Therefore, Figure 7 and Figure 10 indicate that the height of separation zone appears to be around 7.5 m/s.

In the case of Model-2M, wind direction angle of 90° shown in Figure 11, RMS value is maximum at z=10 near the windward separation point (y≤10). Then RMS value is maximum at z=30 on the leeward side (y≥50). Mean wind velocity at the height of maximum RMS value is approximately 5 m/s. Therefore, the height of separation zone appears to be around 6 m/s in Figure 7.

Compared with Figure 10 from the viewpoint of geometry, depth is equal but windward wall area is double. The height of separation zone is taller than that of Model-1M, wind direction angle of 0°. In the range of y≥30, z≤30 which is considered to be in the separation zone, vertical change of average wind velocity is smaller than that of Model-1M, wind direction angle of 0°. In contrast, vertical change of RMS value is larger than that of Model-1M, wind direction angle of 0°.

In the case of Model-2M, wind direction angle of 0° shown in Figure 12, RMS value is maximum at z=10 near the windward separation point (y≤10). Then RMS value is maximum at z=20 on the leeward side (x≥50). Mean wind velocity at the height of maximum RMS value is approximately 5 m/s. Vertical distribution of RMS value shows that vertical change of RMS value is large around x=30. In contrast, vertical change of RMS value is small at x≧100. In view of airflow around building roof as shown in Figure 5 and wind velocity distribution as shown in Figure 8, there appears to be a possibility of flow reattachment.

Compared with Figure 10 from the viewpoint of geometry, windward wall is equal but depth is double. It seems that the height of separation zone is not so apart from that of Model-1M, wind direction angle of 0°.

As a result, in the light of the result of visualization experiment and wind velocity measurement, it is likely that separation of airflow mainly depends on the windward façade wall area and in the case of Model-2M, wind direction angle of 0°, there seems to be a possibility of flow reattachment.

## 4. CONCLUSIONS

From the results of visualization experiment and wind velocity measurement of airflow around building roof, the following characteristics were found.

- For improving natural ventilation performance, chimney height should be tall as possible. In case of windward side of rooftop, chimney height can be lowered.
- From the viewpoint of geometry of each model, separation of airflow mainly depends on the windward façade wall area. In contrast, the depth of the model has less effect.
- The value of wind velocity in separation zone is over 3 m/s, which is larger than expected.
- In the case of Model-2M, wind direction angle of 0°, there seems to be a possibility of flow reattachment due to the depth of Model-2M.
- As a future prospect, natural ventilation air flow rate of building with chimney for better natural ventilation design is to be investigated with not only wind pressure coefficient but also wind velocity above the rooftop.

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