Study on the Airflow Structure in Cross-Ventilated Rooms with the Full-Scale Model Experiment

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ABSTRACT

Cross ventilation is one of the most important techniques for maintaining a comfortable indoor environment in hot and mild seasons with less cooling energy. But, at present, it is difficult to design indoor environment under cross ventilation because there is insufficient knowledge to evaluate the effect of cross ventilation quantitatively. Thus the full-scale model experiment has been done in a large wind tunnel to examine the airflow property in the cross-ventilated space. The purpose of this paper is to clarify the airflow structure in the cross-ventilated rooms.
Main current region, rebounding and changing direction, deflected flow, surface flow and circulating flow are confirmed as key factors determining the air flow structure in cross ventilated space. Air current basically goes straight. But after colliding the obstacles, the flow changes the direction, and the deflected flows are formed over and/or under the main current. And when there is enough space beside the main current region, the circulating flow is formed in each room.
The room mean velocity is determined by the path of air current. When main current appears clearly, relatively low value of the mean velocity appears in one room. And when main current is divided, the room with inflow opening has relatively high velocity.

KEYWORDS

Cross ventilation, Wind Tunnel Experiment, Full-Scale Model, Airflow Structure

INTRODUCTION

Cross ventilation is one of the most important techniques for maintaining a comfortable indoor environment in hot and mild seasons with less cooling energy. But, at present, it is difficult to design indoor environment under cross ventilation because there is insufficient knowledge to evaluate the effect of cross ventilation quantitatively. Especially, the property of indoor airflow is important in the heat exhaust from buildings and the thermal comfort of occupants. The property of indoor airflow has been examined by the visualization (McCutchan et al., 1952) and velocity measurement in scale models and buildings, but the understanding of the detail of airflow distribution remains as an issue by the measurement limitation. Thus the full-scale model experiment has been done in a large wind tunnel to examine the airflow property in the cross-ventilated space. The purpose of this paper is to clarify the airflow structure in the cross-ventilated rooms. The airflow velocity field is measured in detail in the model, and the airflow structure is examined by three-dimensional mean velocity and turbulence characteristic for the understanding of the property of cross-ventilated space.

EXPERIMENTAL METHOD

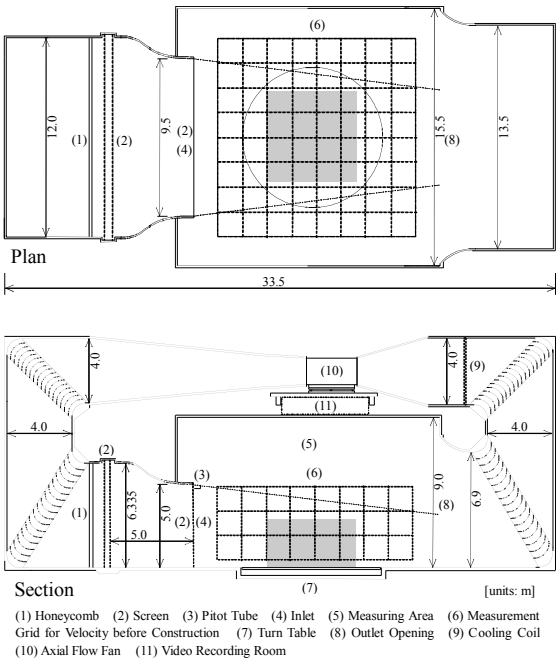

Figure 1: Plan and of the Wind Tunnel

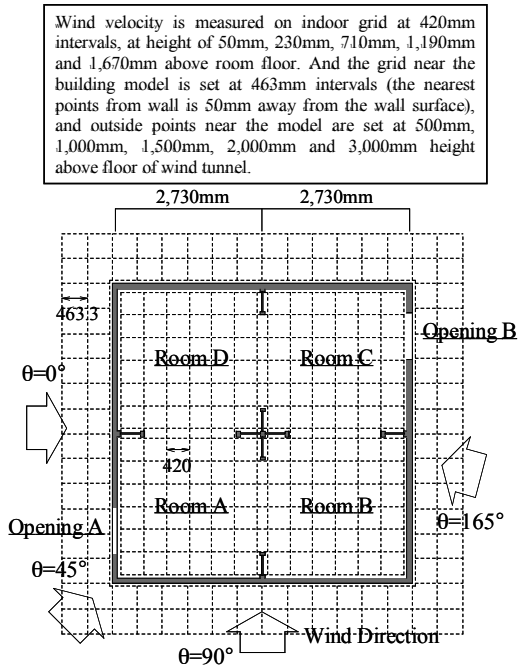

Figure 2: Building Model and Measurement Points

The plan and section of the wind tunnel for cross ventilation is shown in Figure 1. The wind tunnel was constructed to examine the property of airflow in and around a full-scale building model. The wind tunnel has six fans (1.5m in diameter, the maximum output of a fan is 37kW) and the cooling coil to keep under 25 degree centigrade. The range of the wind speed in the working section is 1.0-5.0 m/s, and its distribution was checked to be close to uniform before the construction of the building model (Sawachi et al., 1999). In the experiment of the paper, the average wind speed is set at 3 m/s on inlet side.

The plan of the building model is shown in Figure 2. It has dimensions W=D=5,560 mm and H=3,000 mm and has four rooms. It has two large openings (W=860 mm, H=1,740 mm), which are set at diagonal position of the building model. Wind direction is set at every 15 degree (0° – 165°) by rotating the building model on turntable. The measurement points are set on the grid inside and near the building model, and the measurement is done on five different heights, 50 mm, 230 mm, 710 mm, 1,190 mm, 1,670 mm and 2,100 mm above the floor as for indoor grid. Airflow velocity is measured by using two types of the three-dimensional ultrasonic anemometers, WA-390 (the response time is 0.5 second) and DA-600 (the response time is 0.05 second) of KAIJO.

RESULTS

Velocity Vector on Horizontal Plane at 1,190mm Height above Floor

Figure 3 shows the vector diagram of 0-165° on horizontal plane, which is composed of two heights, at 1,190 mm height above the floor (= 1,690 mm above the floor of the wind tunnel) in the model, and 1,500 mm height above the floor of the wind tunnel around the model. Opening A (Room A) is the windward side in the case of wind direction 0-60° and 90°, and Opening B (Room C) is the windward side in 75° and 105-165°.

The inflow angle at Opening A changes for the wind direction, in the case of 0-60°. In

the case of 15°, the main current flows in almost vertically. In 45°, the current collides with the pillar and walls at center in the model, and diverges in two directions. In the case of 75° and 90°, the ventilation rate is relatively low, but there is main current clearly in Figure 3 (if vector is scaled up). In the case of 105-165°, main current in room C flows along the surface due to the Coanda effect, and there are circulating flows in Room B, C and D.

Velocity Vector on Horizontal Plane of Six Height

Airflow structure is examined in detail from airflow distribution in each height. Figure 4 shows the vector diagram of two cases (wind direction: 15°(left), 165°(right)) on horizontal plane at 50 mm, 230 mm, 710 mm, 1,190 mm, 1,670 mm and 2,100 mm height above the floor.

Main current path appears in Room A→B→C in wind direction 15°, and Room C→D→A in 165° changing the direction. After the colliding with the obstacles (walls and sidewalls) and changing the direction, main current seems to basically go straight because of inertia.

And there are the deflected flows near the wall and the sidewall (around the point 1-3 (15°), point 5 (165°) and so on). The deflected flows go over and/or under the main current with the different direction after colliding with walls at a large angle (around the point 1', 3'(15°) and 5'(165°)). In the case of 165°, rebounding flow at point 5' forms returned flows in the top and bottom layer in Room A→B→C. The returned flow also appears slightly in Room C→D→A in 15°.

When the main current collides with walls at a small angle (relatively parallel

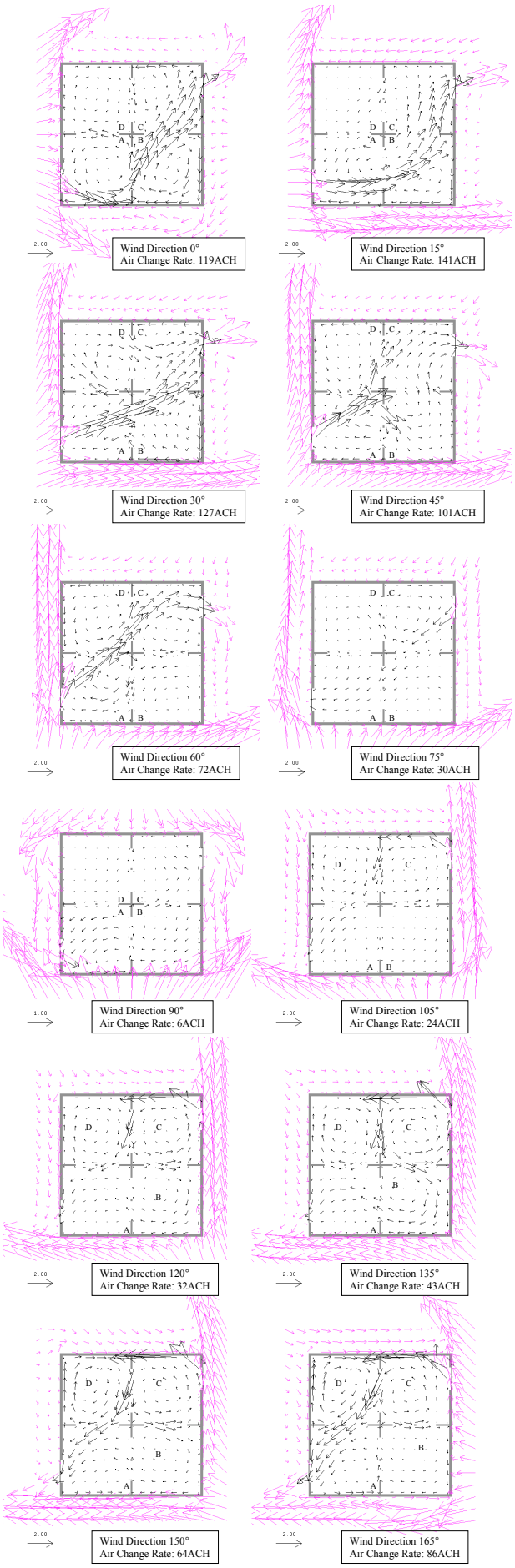

Figure 3: Airflow Distribution on Horizontal Plane at 1,190mm height

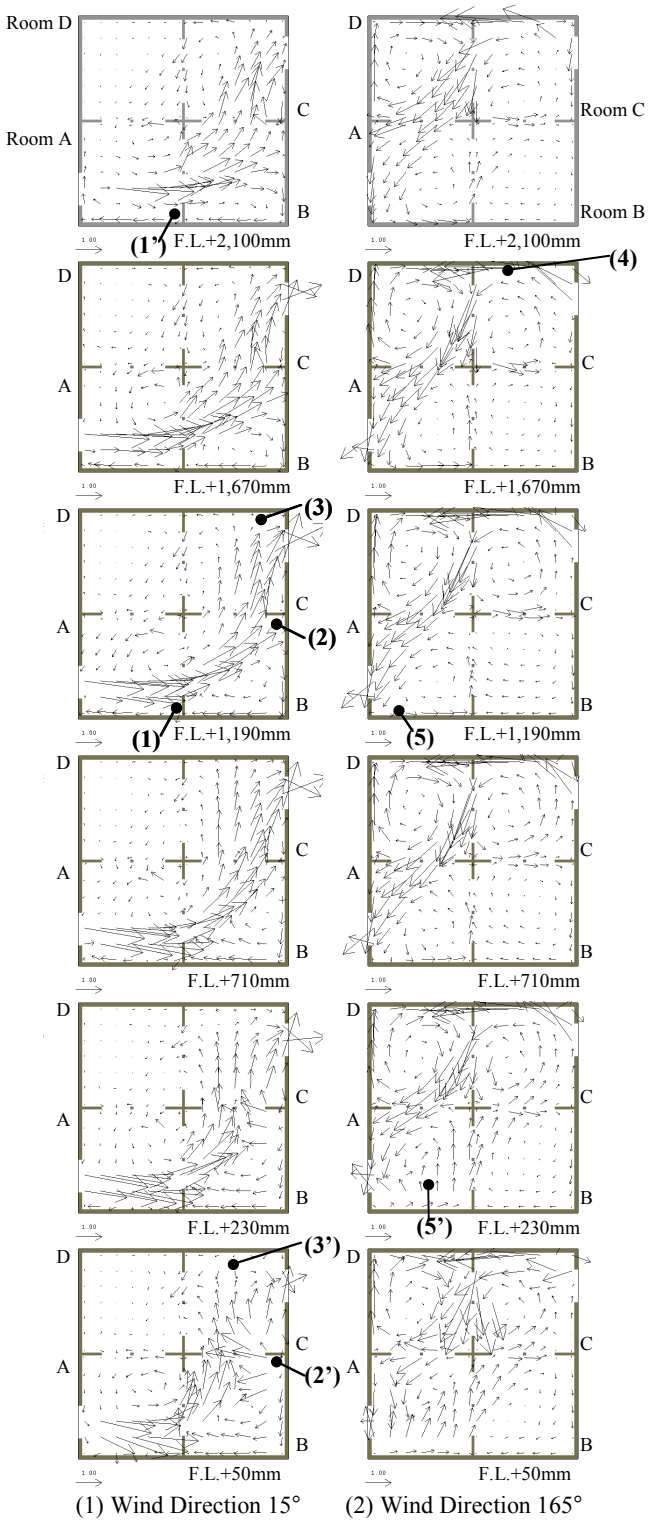

Figure 4: Indoor Airflow Distribution on Horizontal Plane of Six Height

to the surface), it goes along the surface due to the Coanda effect (point 4 (165°)). And the circulating flows are formed beside the main current if there is enough space (Room A, C, D in 165°).

Main current region, changing direction, deflected flow, rebounding, surface flow and circulating flow are confirmed as key factors determining the airflow structure in cross-ventilated rooms.

Mean Velocity Profile in Each Height

Difference of airflow profile is examined. Figure 5 shows the mean velocity profile, which is averaged mean velocity at 49 points at each height in each room. There is no remarkable difference in the mean velocity profile in each room, except at 2,100 mm height that is higher than the top of openings. And when the airflow velocity is compared in four rooms, it is classified into the three patterns

A) Only one room has lower value of the mean velocity (15° and 165° in Figure 5).
B) Only one room has higher value of the mean velocity (45°, 75° and 135° in Figure 5).
C) Four rooms have each value of the mean velocity (105° in Figure 5).

Pattern A is the case that main current appears clearly as 0, 15, 30, 60 and 165°. Pattern B is the case that the room with the inflow opening has high velocity, and the main current is divided into small current with pillars and walls as 45, 75, 120 and 135°. And pattern C is the case that the current mainly passes through one room after colliding the pillars and walls.

Frequent Distribution of Mean Velocity

Figure 6 shows the frequency of the normalized mean velocity in each room. The normalized mean velocity is obtained from normalizing by the average value and the standard deviation of 980 measurement points at five heights (except 50 mm height above floor).

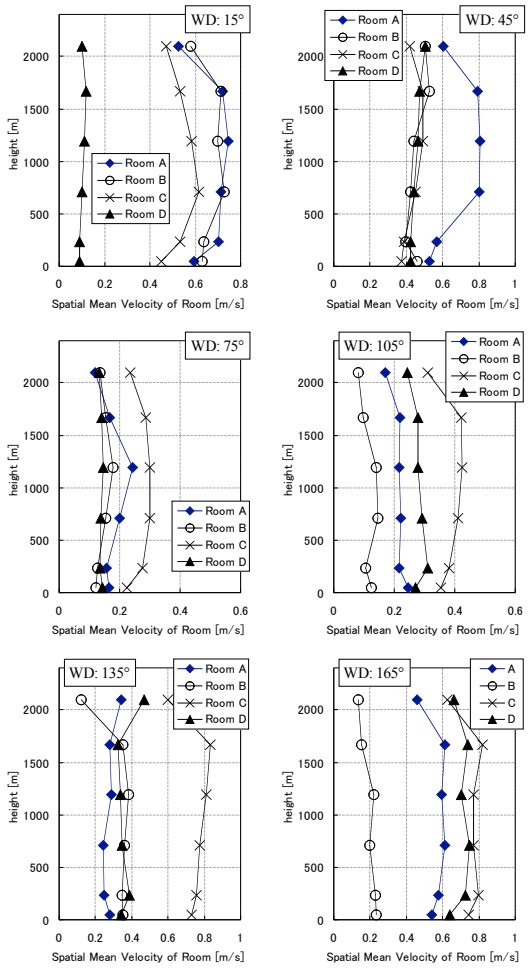

Figure 5: Spatial mean velocity of Room A-D at each height

In the case of wind direction 15° which has the highest ventilation rate, the main current appears clearly and the room mean velocity is the highest in Room A with the inflow opening, but the mode of the normalized velocity in Room A is smaller than Room B and C. But Room A has some low peaks at the high velocity class (in the range of the velocity = 1.5 -3.0 m/s) and the peaks show the high velocity points in the main current. In Room B, the mode is in the range of 0.5 - 0.6 m/s, and Room B has larger area in the middle velocity range than Room A, which has small area in the high velocity range. The case of 165° also denotes the same tendency in Room C and D. In the case of 45°, Room A with the inflow opening has the smallest mode, but has some peaks in the high velocity range. Room B and C has larger mode than

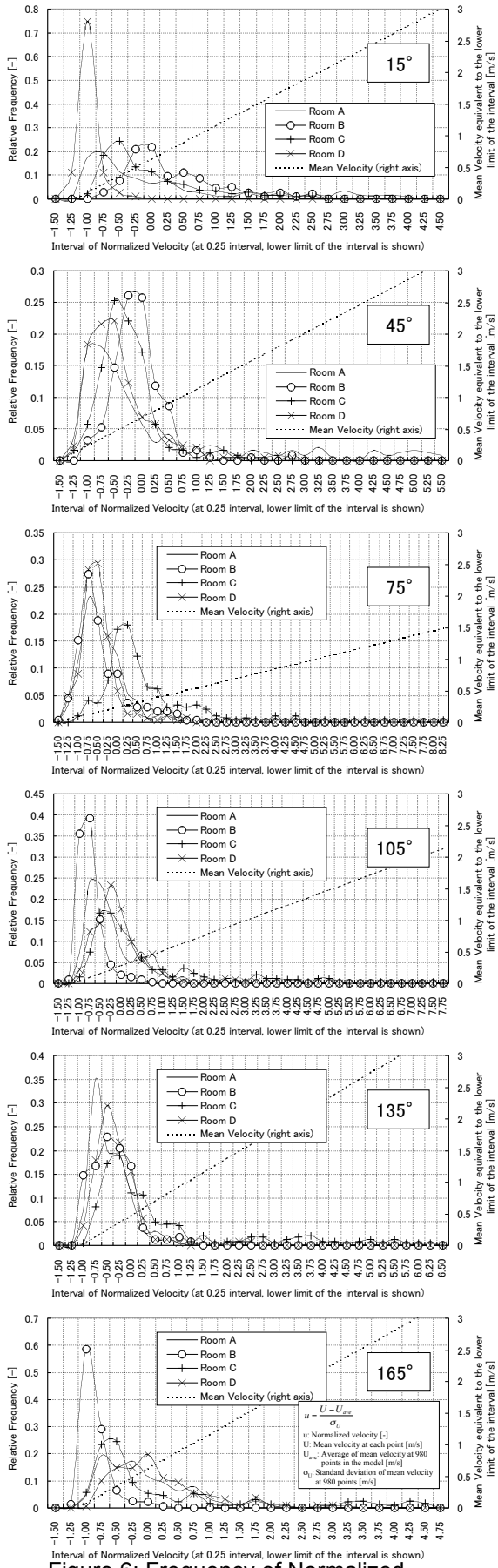

Figure 6: Frequency of Normalized Mean Velocity of Room A-D

Room A.
In the case of wind direction 75°, the room mean velocity in the room with the inflow opening (Room C) is larger than other three rooms, and the mode of the velocity is also larger than other rooms. This trend is different from the case of 15°, 45° that have relatively high ventilation rate. In the case with small ventilation rate, the upstream room has advantage to take the sensation of coolness.

CONCLUSIONS

The airflow velocity field is measured in detail in the full-scales model, and the airflow structure is examined by the mean velocity for understanding the property of cross-ventilated space. Conclusion is as follows.

1) Main current region, rebounding and changing direction, deflected flow, surface flow and circulating flow are confirmed as key factors determining the air flow structure in cross ventilated space. Air current basically goes straight. But after colliding the obstacles, the flow changes the direction, and the deflected flows are formed over and/or under the main current. And when there is enough space beside the main current region, the circulating flow is formed in each room.
2) The room mean velocity is determined by the path of air current. When main current appears clearly, relatively low value of the mean velocity appears in one room. And when main current is divided, the room with inflow opening has relatively high velocity.
3) The mode of the mean velocity in the room with inflow opening is basically lower than downstream rooms though the room with inflow has high velocity region in main current.

The property of the actual cross-ventilated space is more complex, because there is the changing of wind direction and velocity in the actual environment. Thus it is important to examine the property in the cross ventilated space by the wind tunnel experiment and the measurement in actual residential buildings.

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