ABSTRACT
The wind pressure coefficient is the basic driving force of wind-induced natural ventilation. The wind velocity along the building wall is also important for wind environment in balcony (veranda) or windows and is the moment of inertia for the air flowing into rooms. These two values of the five-storied apartment building with/without veranda were measured by wind tunnel test using scaled model. The experimental conditions are the façade type, the shape of veranda and wind direction. The distribution of wind pressure coefficient is not influenced so much by the type of veranda; parapet or fence. Basically, the distribution of wind pressure coefficient on the building façade depends mainly on the wind direction. Also, the existence of veranda has little effect on the wind pressure distribution. At wind direction $\theta=0^\circ$, the local wind velocity along the façade wall is much affected by the type of veranda. Parapet type tends to diminish the local velocity. Partition walls in veranda make the velocity along the wall more uniform and around one fifth. At windward directions, the more wind pressure coefficient the less wind velocity along the wall if there is no partition in veranda because of Bernoulli's equation.

KEYWORDS
wind-induced ventilation, wind pressure coefficient, local wind velocity, balcony

INTRODUCTION
The wind pressure coefficient is important for predicting the wind-induced natural ventilation rate. Many textbooks on building ventilation or building aerodynamics mentioned its distribution on the building wall (e.g. Baturin 1972, Aynsley et al. 1977, Etheridge and Sandberg 1996, ASHRAE 2005). The wind pressure coefficient distribution on the building wall depends on the building shapes, the wind direction, the building façade elements and so on, but there seemed to be few researches from the viewpoint of building façade elements.

Authors have proposed the reasonable prediction method of cross-ventilation rate of the room with large openings that integrates the prediction method of three components of wind pressure coefficient, wind velocity along the building wall and pressure loss coefficient of the room (Kotani and Yamanaka 2006a, 2006b). It was proposed that the wind pressure coefficient can be predicted by the authors' previous proposed method (Yamanaka et al. 1991). The wind velocity along the building wall will be predicted by the previous experiment as well (Yamanaka et al. 1992). Authors have prepared these two values for the various building shapes and wind directions, and also proposed the regression equations based on experiments for the wind pressure coefficients. However these experiments were conducted only for the buildings without any façade elements. Therefore the influence of the building façade elements on the wind pressure coefficients and the wind velocities along the building wall are investigated in this paper. These two values of the five-storied apartment building with/without balcony (veranda) are measured by wind tunnel test using scaled model. The part of this research has already presented in the previous research (Nakamori et al. 2003).
EXPERIMENTAL METHOD

A 1/60 scaled apartment building model was set on the floor of wind tunnel as shown in Figure 1. An atmospheric boundary layer wind tunnel with approaching flow of 1/5 power law was used. Figure 2 shows the profiles of velocity and turbulent intensity of it. Here the height of the building model is 25 cm. Large-scale turbulence is generated by windward lattice, and the roughness elements on the tunnel floor generate the small-scale turbulence and the velocity profile of boundary layer. The reference external wind velocity is 10 m/s at 900 mm height above the tunnel floor. The building model is assumed as five-storied apartment building with ten rooms for each floor. Figure 3 shows the building model and its measurement points. Veranda and partition wall as the building façade elements can be installed and removed according with the experimental conditions.

Table 1 shows the experimental conditions. The façade types, the shapes of veranda and external wind directions are changed. For the shapes of veranda, parapet means the blocked wall and fence has continuous vertical gap with its porosity of about 90% (see Figure 3). Partition assumed the partition wall between neighbors located inside veranda. The definition of wind direction is shown in Figure 4.

Wind pressure coefficient

Wind pressure coefficients were measured at 50 points on the building wall (see Figure 3). The pressures were measured by the pressure transducer (Validyne, MP45) during 30 seconds with its sampling frequency of 100 Hz and those averaged values at each measurement point were calculated. The wind pressure coefficients were obtained from dividing these values by the dynamic pressure at the building height that was calculated from measured reference wind velocity.

Wind velocity along building wall

Wind velocities along building wall were measured at 50 points in front of the wind pressure measurement points. The velocities were measured by the hot-wire anemometer (Kanomax, 7102) during 30 seconds with its sampling frequency of 100 Hz and those averaged values at each measurement point were calculated. Figure 5 shows the measurement setup and measurement point of wind velocity. The hot-wire anemometer has I-type probe and the wire is always set perpendicular to
the wall to measure the wind velocity parallel to the wall. From the previous detailed velocity measurements in the vicinity of wall, the boundary layer of the wall was decided as less than 5 mm, so the measurement point of wind velocity was set at 5 mm from the wall. In all cases with/without veranda, this measurement point was used. Obtained wind velocities were normalized by the wind velocity at the building height that was calculated from measured reference wind velocity.

RESULTS AND DISCUSSIONS

Wind pressure coefficient

Figure 6 shows the distribution of wind pressure coefficient in the case of wind direction of 0 degrees with veranda of parapet type. The view of figures is the elevation from the front of the building and white lines mean the bottom height of the parapet for the case without partition, and the bottom height of the parapet and partition position for the case with partition. Significant differences cannot be seen among cases. There is a little difference in the case without partition. The wind pressure coefficient in the upper corner shows rather small value, because the impinging air with high velocity around the stagnation area tends to flow to the side of the building along the parapet slab.

Figure 7 shows the distribution of wind pressure coefficient in the case of wind direction of 0 degree with veranda of fence type. The tendency is almost the same as the parapet type. There is a little difference in the case with partition. The stagnation area seems to locate at a little bit higher position than that in other cases, but it is not remarkable difference.
Figure 8 shows the distribution of wind pressure coefficient for wind direction of 45 degrees. Almost the same distribution can be seen in case of the veranda without partition. Partition makes more uniform distribution vertically, but its influence is small. The distribution for 135 degrees is shown in Figure 9. This case, the façade is in the wake of the building, so the wind pressure coefficient shows negative value. The distributions are almost the same. It can be concluded that the building façade elements do not influence so much on the wind pressure coefficient.

Wind velocity along building wall

Figure 10 shows the distribution of normalized wind velocity in the case of wind direction of 0 degrees. The left side figure shows the distribution on the façade, the right one shows the horizontal distribution on each floor. The distributions are changed by veranda type and with/without partition. In the case of parapet type without partition, the velocity at the highest floor decreases in half, though that of the fence type without partition does not change. At the lower floors, both types show the velocity decrement. The partition causes the large velocity decrement to about one fifth compared to the wall without any façade elements. Also the vertical velocity distribution becomes more uniform.

These tendencies do not correspond to the results of wind pressure coefficient, because the wind velocity means the local wind velocity inside the veranda. The wind pressure of the wall is dominated by the surrounding pressure distribution generated by building itself, so the façade elements are not so important. Outside the veranda, the wind velocity may be explained by the Bernouilli’s equation, that is the more wind pressure the less wind velocity.
Figure 11 and 12 show the distribution of normalized wind velocity in the case of wind direction of 45 degrees and 135 degrees. Similar tendencies with 0 degree case can be seen. In the case of 45 degrees, the wind velocity increases gradually at the downstream of the wind. Façade elements diminish the velocity and especially partition makes uniform distribution. Wind direction of 135 degrees means that the façade locates inside the wake of the building. Even in this case, the influence of façade elements is similar.

The wind pressure coefficient and the wind velocity along the wall can be compared from Figure 6 to 12. As mentioned above, outside the veranda, the wind velocity may be explained by the Bernouilli's equation, so that the more wind pressure coefficient the less wind velocity along the wall in the case without partitions in veranda when the wind directions are 0 and 45 degrees (windward directions).

**CONCLUSIONS**

The distribution of wind pressure coefficient is not influenced so much by the type of veranda; parapet or fence. Basically, the distribution of wind pressure coefficient on the building façade depends mainly on the wind direction. Also, the existence of veranda has little effect on the wind pressure distribution. The wind pressure of the wall is dominated by the surrounding pressure distribution generated by building itself, so the façade elements are not so important. At wind direction of 0 degrees, the local wind velocity along the façade wall is much affected by the type of veranda. Parapet type tends to diminish the local velocity. The partition causes the large velocity decrement to about one fifth compared to the wall without any façade elements and makes the vertical velocity distribution more uniform.
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