Local dynamic similarity concept as applied to evaluation of discharge coefficients of ventilated buildings. Part 3: Simplified method for estimating dynamic pressure tangential to openings of cross-ventilated buildings

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ABSTRACT

A simplified method was investigated for estimating the dynamic pressure tangential to an opening (P_t) with Irwin's surface wind sensor. The wind velocity measured by this sensor was broadly consistent with the value measured by a hot-wire anemometer. Moreover, P_t calculated from the wind velocity measured by the surface wind sensor is compared with that derived from the difference between total pressure (P_T) and wind pressure (P_W) measured directly at the opening was compared. This shows that P_t can be estimated by the surface wind sensor.

1. INTRODUCTION

To predict the ventilation flow rate based on the local dynamic similarity model, it is necessary to derive the value of P_R^* given in equation (1) as a new parameter.

$$P_R^* = \frac{P_R - P_W}{P_t} = \frac{P_R - P_W}{P_T - P_W} \quad (1)$$

where:

- P_R: Room pressure,
- P_W: Wind pressure,
- P_t: Dynamic pressure tangential to the opening,
- P_T: Total pressure.

For deciding this parameter, it is necessary to determine P_t or P_T in addition to P_W. When the position of the opening is determined, it is possible to directly determine the value of P_T with pitot-tubes, as already reported (Kurabuchi, 2005). However, when we consider "the determination of the opening -position during design stage", this measuring method is not suitable for practical application. This paper addresses the issue of simplified method for estimating P_t by using the surface wind sensor developed by Irwin (1981).

2. IRWIN'S SURFACE WIND SENSOR

Irwin's surface wind sensor has been developed for measuring wind velocity within a horizontal plane at the level of pedestrians in a wind tunnel model. It is possible to estimate wind velocity at an arbitrary height from the pressure difference in the vertical direction near the floor surface independently of the wind angle. Figure 1 shows the outline of the surface wind sensor used in the present study.

A pressure-sensor-hole is provided to enclose a pressure-sensor-tube. The heights of sensor -tubes used in the study were 3 mm and 5 mm. By using the pressure -difference between the sensor –tube and sensor –hole, the wind velocity is obtained from equation (2).

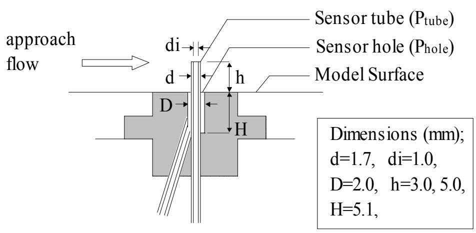

Figure 1: Geometry of the surface wind sensor.

$$U_t = a + b \times (P_{hole} - P_{tube}) \quad (2)$$

where:

- U_t: Wind velocity tangential to the wall surface
- P_{hole}: Pressure measured by sensor-hole
- P_{tube}: Pressure measured by sensor-tube
- a, b: Regression coefficients

Regression coefficient a and b in equation (2) are constants determined by air flow characteristics. Sensors were installed at the center of the wall surface, and the values were calibrated for wind angles of 22.5°, 45°, 67.5°. As shown in Figure 2, the hot-wire anemometer was installed from above the model so that the probe was at a position perpendicular to the wall surface. The approach-flow was a boundary layer flow, and the wind velocity was varied by the wind tunnel fan. Regression coefficients for the height (hs) and the wind angle are shown in Table 1.

3. OUTLINE OF EXPERIMENT

The outline of the experiment for U_t and P_t measurement is shown in Figure 3. The approach flow was a boundary layer flow with a wind velocity of 7 m/s at the top edge of the model. Here, it is assumed that wind velocity and wind velocity pressure at the top edge of the model are standard wind velocity and standard pressure, respectively. Subsequently, standardized values based on these values are used in all parameters for wind velocity and pressure.

The wind angles used in this study were 22.5°, 45°, and 67.5°. The wall surface to be evaluated was on the upstream side, and was installed with 21 measuring points. The measurement of U_t was performed by the hot-wire anemometer and the surface wind sensor. The measuring method of the hot-wire anemometer was identical to that of the sensor calibration. The sensor pressure was measured simultaneously all points by a multi-point pressure transducer. Measurements were made on the model with two arrangements as shown in Figure 4, i.e. the model alone (Case 1) and the model with another one in front of the wall surface to be evaluated (Case 2).

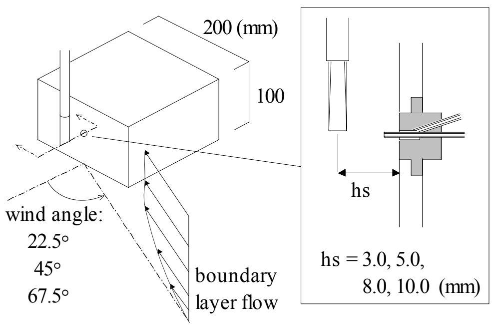

Figure 2: Outline of the experiment for calibration of the surface wind sensor.

4. RESULT AND DISCUSSION

4.1 Interference between sensors

Prior to the measurement of U_t and P_t, the influence of interference between sensors when measurements were made simultaneously at 21 points was confirmed. For measurement point a-2, the differential pressure between P_{hole} and P_{tube} measured individually and simultaneously along with other sensors are compared in Figure 5. There was almost no difference between the two cases. Therefore, the results of

Table 1: Regression coefficients of surface wind sensor.

h	hs	Wind angle	a	b
3	3	22.5°	0.09	1.31
		45°	0.17	1.36
		67.5°	0.13	1.49
	5	22.5°	0.12	1.25
		45°	0.19	1.40
		67.5°	0.18	1.51
	8	22.5°	0.07	1.21
		45°	0.23	1.39
		67.5°	0.17	1.55
	10	22.5°	0.10	1.18
		45°	0.22	1.39
		67.5°	0.22	1.56
5	3	22.5°	0.09	1.24
		45°	0.11	1.31
		67.5°	0.07	1.43
	5	22.5°	0.12	1.19
		45°	0.13	1.34
		67.5°	0.11	1.45
	8	22.5°	0.07	1.15
		45°	0.17	1.32
		67.5°	0.10	1.49
	10	22.5°	0.10	1.12
		45°	0.16	1.33
		67.5°	0.15	1.50

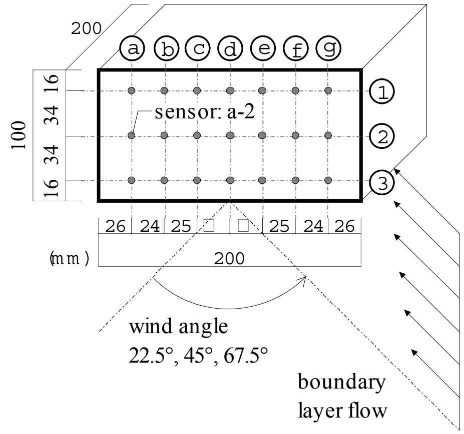

Figure 3: Outline of experiment for U_t and P_t measurement.

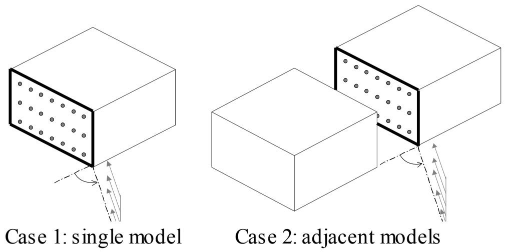

Figure 4: Model arrangements.

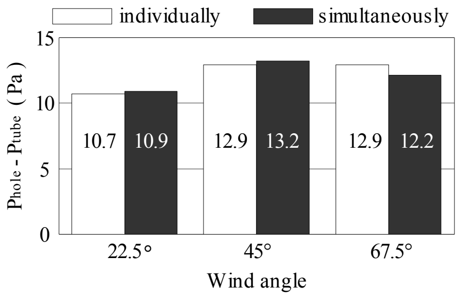

Figure 5: Comparison of Phole-Ptube measured individually or simultaneously at the point of a-2.

subsequent measurements were determined simultaneously along with 21 points.

4.2 Wind velocity tangential to wall (U_t)

In Figure 6, the values of U_t measured by the surface wind sensor (h=3, 5) are compared with the values measured by the hot-wire anemometer. The measuring position was 5 mm from the wall surface. For each wind angle, in Case 1, the results were broadly consistent with the hot-wire anemometer results. In Case 2, however, the results were not as consistent as in Case 1. This may be attributed to the fact that the air flow characteristics near the measuring point are very complicated on the windward model and error may have occurred due to the directivity of the hot-wire anemometer. When the measurement results of the sensor were compared with those of the hot-wire anemometer at other positions from the wall surface, similar results were obtained.

4.3 Wind pressure

The sensor-hole was located at the same position as in the wind pressure measurement. If it is supposed that wind pressure can be simultaneously measured by the sensor-hole, the efficiency of the parameter-measurement for the prediction of ventilation flow rate can be extensively improved. Wind pressure directly

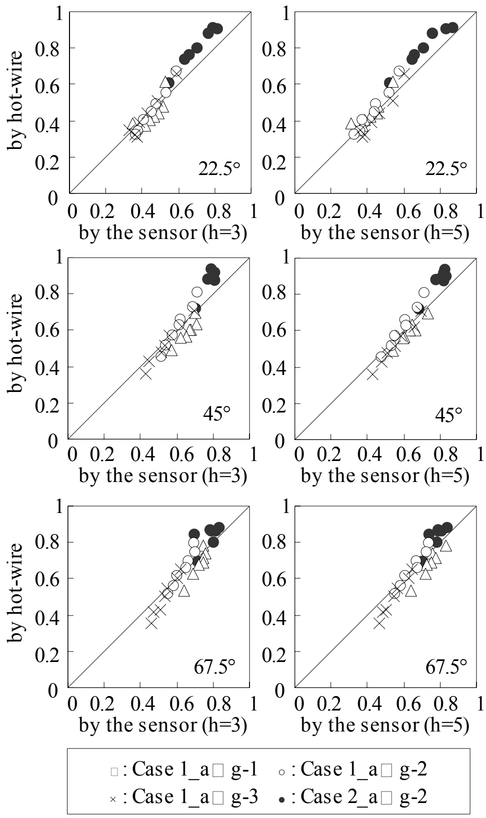

Figure 6: Comparison of U_t measured by surface wind sensor and hot-wire anemometer 5mm away from wall surface.

measured is compared with P_{hole} as shown in Figure 7. These figures indicate that P_{hole} is broadly consistent with the wind pressure. Therefore, it is possible to apply P_{hole} to wind pressure.

4.4 U_t distribution near wall surface

In predicting ventilation flow rate, the question arises of how far from the wall surface should the wind velocity be determined If it is supposed that the value of P_T directly measured by pitot-tube at the opening is the correct value, P_t can be obtained by subtracting P_W from P_T, and U_t can be determined. The U_t distribution near the wall surface at the central height of the model in Case 1 is shown in Figure 8. This figure shows the results of U_t calculated backward from P_T directly measured at the opening, measured by the sensor and the hot-wire anemometer. U_t measured by the sensor and the hot-wire anemometer were very high values on the windward side compared to the value calculated backward from P_T. When the wind angle is 22.5°, the measuring point is near the collision area of the approach flow, and it is difficult to perform measurement in view of the structure of the surface wind sensor. When the wind angle is 67.5°, there may be an influence from separation flow at the windward end of the model.

A point from the wall surface where U_t is consistent with the value calculated backward from P_T changes according to the wind angle and the position on the wall surface. Therefore, it is

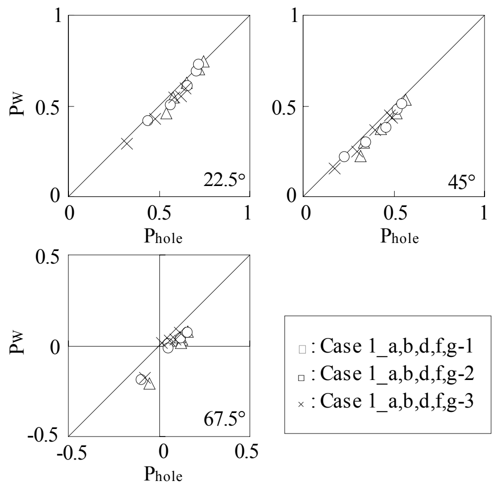

Figure 7: Comparison of P_{hole} and P_W.

difficult to decide the point to measure U_t. More study on this subject is necessary, considering the error in the prediction of ventilation flow rate.

4.5 Wall surface distributions of P_t, P_W, and P_T

Wall surface distributions of P_t, P_W, and P_T measured directly at the opening and measured by the surface wind sensor (h=5 mm) in Case 1 and Case 2 are shown in Figure 9 and Figure 10 respectively.

The distribution of P_t is obtained from the difference between P_T and P_W directly measured at the opening and from wind velocity 5 mm from the wall surface measured by the sensor. The distribution of P_T is obtained from direct -measurement at the opening and the sum of P_t and P_W measured by the sensor. The sensor results were broadly consistent with those

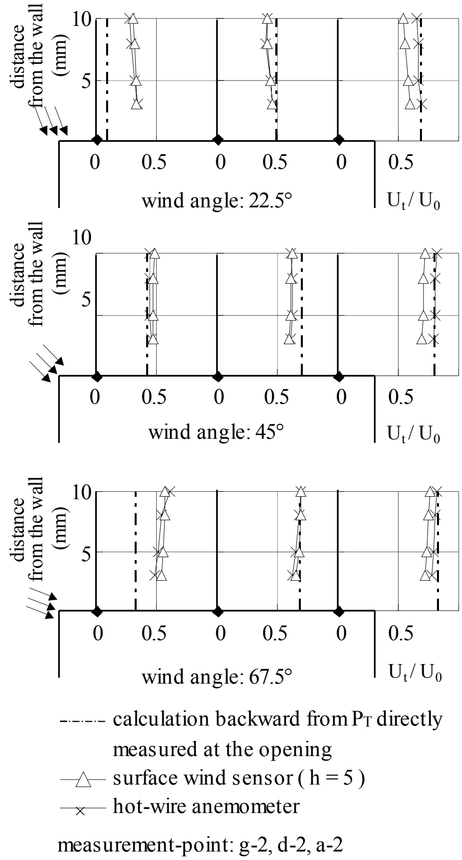

Figure 8: U_t distribution near wall surface at points g-2, d-2, and a-2.

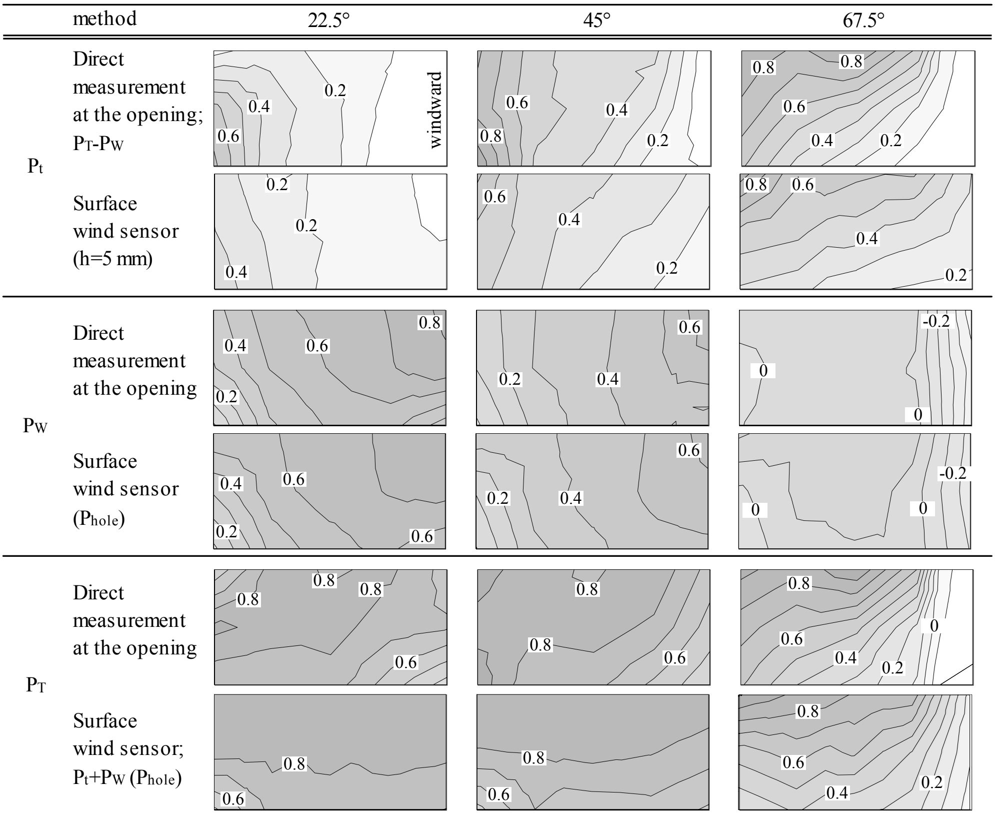

Figure 9: Wall surface distributions of P_t, P_W, and P_T measured directly at opening and measured by surface wind sensor (h=5 mm) in Case 1.

measured directly at the opening in each pressure parameter and case. Thus, it was confirmed that a simplified estimation of P_t and P_T can be made by using the surface wind sensor. However, for measurement accuracy, it is necessary to consider the error in the prediction of the ventilation flow rate.

The time required for direct measurement of P_T distribution on the wall surface of all wind angles was about 30 hours. In contrast, when the sensor was used, the time required was only 1.5 hours including the time for calibration of the sensor.

5. CONCLUSION

In this study, a simplified method for estimating P_t with Irwin’s surface wind sensor was investigated. The findings can be summarized as follows:

- Wind velocity tangential to the wall surface can be measured by using a surface wind sensor.
- Pressure measured by a sensor-hole can be evaluated as wind pressure.
- P_t and P_T measured by the sensor are broadly consistent with the results measured directly at the opening.
- As described above, by using a surface wind sensor, pressure parameters required for the prediction of ventilation flow rate based on local dynamic similarity model can be simply measured.

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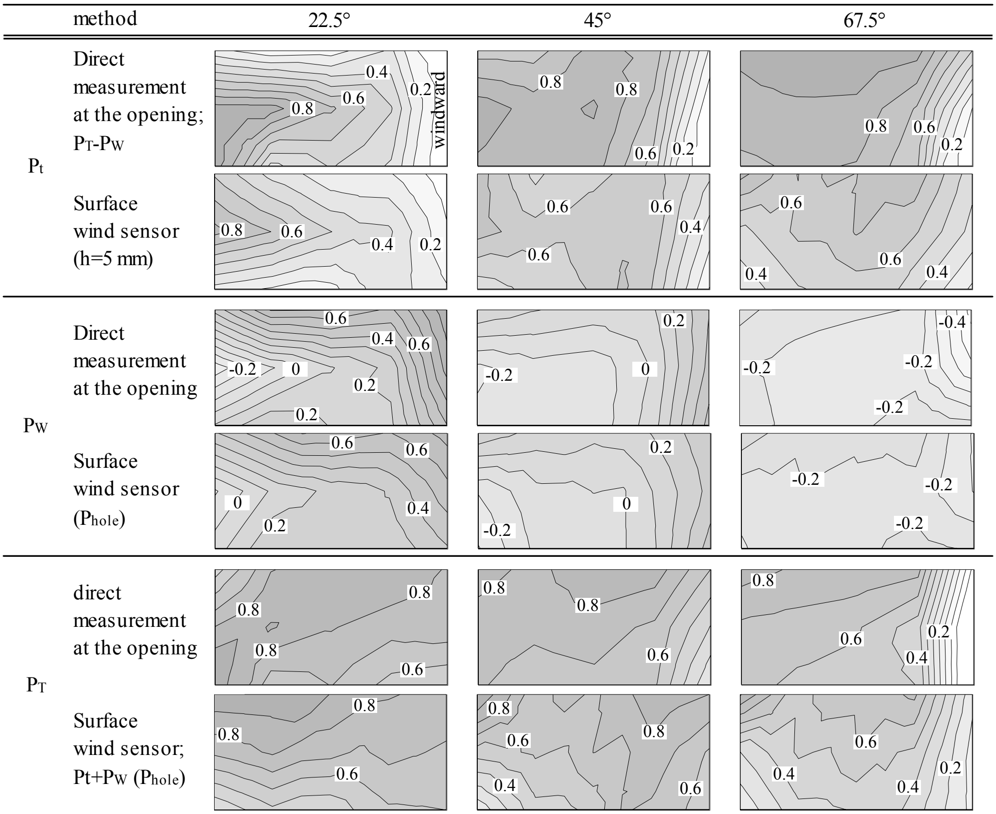

Figure 10: Wall surface distributions of P_t, P_W, and P_T measured directly at opening and measured by surface wind sensor (h=5 mm) in Case 2.

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