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ANALYSIS AND DESIGN OF SINGLE-SIDED NATURAL VENTILATION

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ABSTRACT: The simplicity of opening a window or a door in the building envelope makes single-sided natural ventilation a simple and commonly used principle of ventilation, but even though this type of ventilation seems to be simple the boundary conditions are very complex and still not fully understood. To increase the knowledge of single-sided ventilation and to develop design methods to ease the design process several full-scale wind tunnel experiments have been performed on a building sized 5.56 x 5.56 x 3.00 m ventilated by single-sided natural ventilation. This paper describes the results from the measurements evaluated on the basis of the air change rate, which has been measured both by use of tracer gas and by measured air velocities in the opening. Both the effect of wind velocity, temperature difference and incidence angle of the wind are discussed together with future possibilities of developing new design methods for single-sided ventilation.
Keywords: Single-sided natural ventilation, ventilation rate, wind velocity, temperature difference.

NOMENCLATURE

A	Area of the opening (m^2)
h	Height of the opening (m^2)
Q	Volume flow rate (m^3/s)
T	Temperature (°C)
u	Velocity (m/s)

SUBSCRIPTS:

eff	Effective
m	Mean value
10	Height of 10 m

1. INTRODUCTION

Natural ventilation is a sustainable technology that, either as a “stand alone” system or assisted by mechanical fans (hybrid ventilation), can contribute to reduction of building energy use and global requirements of greenhouse gas emission reduction.

Single-sided natural ventilation is a simple and commonly used principle. However, the trivial action of opening a window and/or a door in the building envelope or just having some kind of device in the outer wall that allows fresh air to enter the room gives rise to a phenomenon, which is complex to analyse and is influenced by various boundary conditions in a way that is not yet fully understood.

There are a few approximate semi-empirical correlations available for the analysis of airing by window openings affected by buoyancy, wind forces or both, but none of them takes into consideration the influence of changes in wind direction. This lack of knowledge discourages the choice of a solution, whose performances are not well known. To increase the use of single-sided natural ventilation, it is therefore necessary to increase the knowledge of this type of ventilation. This is done in this work by performing and analysing several full-scale wind tunnel experiments. During the experiments the effect of wind direction, wind velocity and temperature difference is investigated. The results obtained from the analysis are described in this paper and will in future work be part of a new design method to ease the design process.

1.1 Calculation of air flow in single-sided ventilation

Previous work has already led to expressions for estimations of the airflow in single-sided natural ventilation. In this present work estimates have been made by use of empirical expressions found by De Gids & Phaff (1982) and by

Warrens & Parkins (1985).

In cases where both wind and buoyancy effects are present the expression by De Gids & Phaff is used. Here the mean velocity is calculated as follows from a given wind velocity and temperature difference across the opening: [1]

$$u_m = \sqrt{(0.001 \cdot {u_{10}}^2 + 0.0035 h \Delta T + 0.01)} \qquad (1)$$

To find the volume flow through the opening expression (2) is used: [1]

$$Q = A_{eff} \cdot u_m = ½ \cdot A \cdot u_m \qquad (2)$$

In cases without buoyancy effect but affected by the wind only expression (3) by Warren & Parkins can be used: [3]

$$Q = 0.025 \cdot A \cdot u_{10} \qquad (3)$$

None of the expressions above takes into consideration the effect of different wind direction and since this is often the case this effect needs to be included.

2. METHODS

To investigate the effect of different wind directions on the air change rate in single-sided natural ventilation several experiments have been performed in the wind tunnel at the Japanese Building Research Institute (BRI). The experiments were made on a full-scale building which can be rotated to measure the air change rate at different wind directions, see Fig. 1.

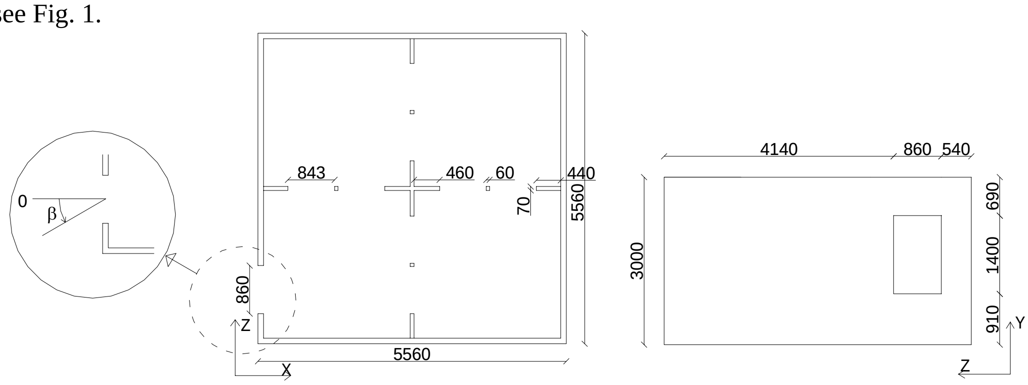

Figure 1. Plan and front of the building together with the definition of incidence angle of the wind. Dimensions in mm

The measurements were carried out for different wind velocities and temperature differences, and the incidence angle of the wind was increased by either 15° or 30° at each experiment until a full 360° rotation was attained, see Table 2. The temperature difference was created with four electric heaters placed inside the building.

Table 2. Experiments made in the wind tunnel.

Case		1	2	3	4	5	6	7	8	9
Temp. diff.	(°C)	0	0	0	5	5	5	10	10	10
Change of angle	(°)	30	15	30	15	15	15	30	15	30
Velocity	(m/s)	1	3	5	1	3	5	1	3	5

During the experiments the velocity profiles in the opening were measured in three vertical lines each with eight ultrasonic anemometers measuring three directions with a frequency of 10 Hz. The anemometers were placed 100 mm from each edge and in the middle of the opening. The temperatures were measured in the same lines in the opening as well as in four columns inside the building with a frequency of 1/15 Hz. Pressure was also measured with a frequency of 10 Hz in six points around the opening, two points on the floor inside the building and a single point on the front wall.

The air change rate was measured and calculated both by the measured velocities in the opening multiplied by the corresponding area and by the use of tracer gas. When using tracer gas the decay method was used where tracer gas was added to the building before the start of the experiment. The decay method requires full mixing of gas which sometimes can be hard to accomplish. To minimize this error during the experiments the gas was collected in 8 points equally distributed in the building. These samples were then mixed in a single container and the gas concentration was measured from here. The results were compared to see if there was any agreement between the two methods (see the result chapter).

3. RESULTS

The aim of the measurements is to find coherence between the air change rate and the wind direction, wind velocity and temperature difference, if any. As the air change rates have been both calculated by the decay method and by the use of velocity measurements these results need to be compared before evaluating the air change rates as a function of incidence angle.

3.1 Method for calculation of volume flow through the opening

The fluctuations in the opening in single-sided ventilation can be very large. This might result in flows that do not affect the air-change rate but just leaves the room again as "clean" air. These fluctuations will affect the measured mean velocity in the opening contrary to the decay method, which will not be affected.

By comparison of the two methods (see Fig. 2) the best agreement is found with low velocities, where the average values of the measured incoming and outgoing air are close to the values found by the decay method. In the cases with high wind speeds the dispersion of the points is larger and a pattern in this case is hard to find. The same tendency is found for temperature differences of 0°C and 10°C. A reason for the large deviation from the decay method in the cases with high velocities can be that the fluctuations in the opening are much larger in these cases than in the cases with low velocities. Larger fluctuations in the opening will affect the velocity profile but as mentioned earlier not necessarily the air change rate. From this investigation it is presumed that the decay method in this case is the most accurate prediction, even though it assumes full mixing in the room, and further use of air change rates is from predictions with the decay method.

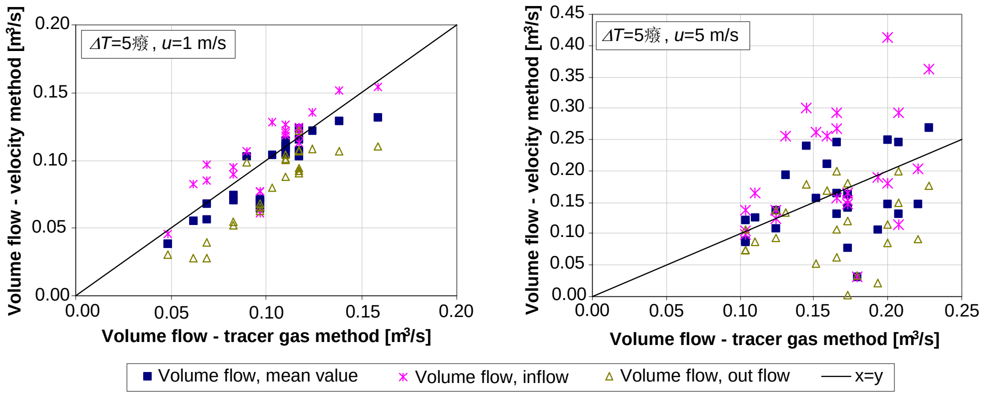

Figure 2. Comparison of volume flows found by decay method and velocity measurements.

3.2 Variation of air change rates at different wind directions

To find the effect on the air change rate from changes in temperature difference across the opening and wind velocity at different wind directions the results are handled both with fixed wind velocities (see Fig. 3) and with fixed temperature differences (see Fig. 4).

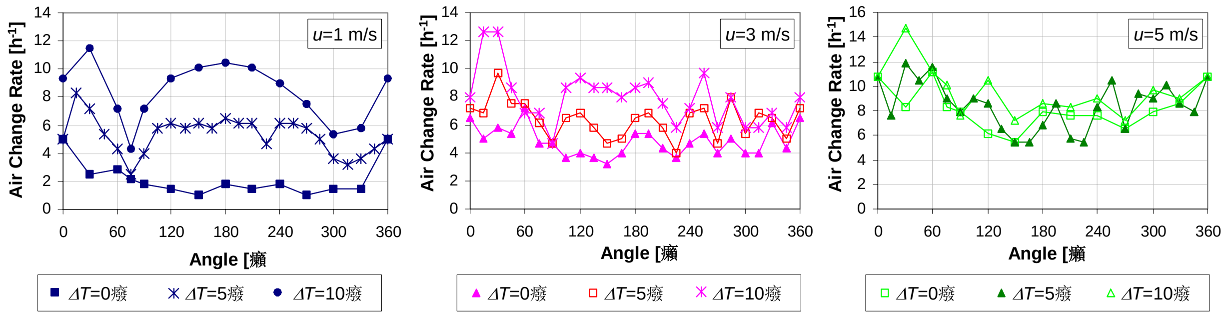

Figure 3. Measured air change rates at fixed wind velocities.

From the plots with fixed wind velocities (Fig. 3) it is found, that increasing the temperature difference will have the largest effect at low wind velocities. Especially in the cases where the opening is at the leeward side (from 105° to 255°) the effect of the temperature difference is large. This indicates that the airflow through the opening in these cases is mainly driven by buoyancy. As the velocity is increased the curves of the air-change rate are approaching each other which show that the buoyancy effect is minimized. When the velocity is increased to 5 m/s the effect becomes difficult to see and is close to non-existing.

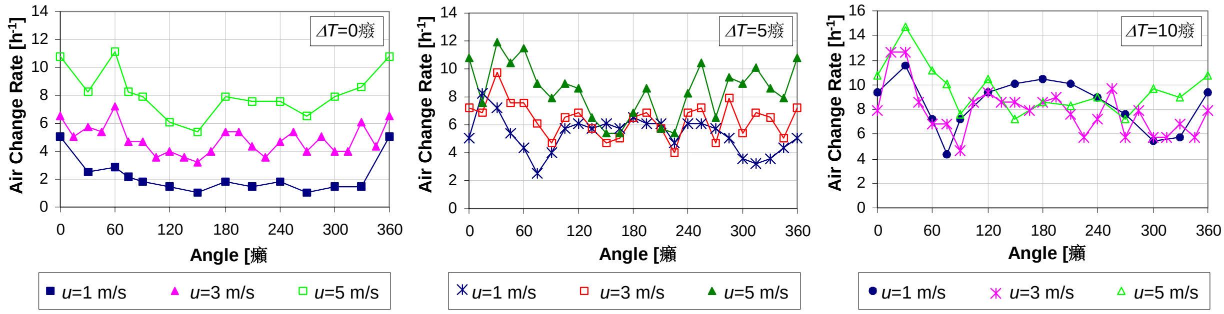

Figure 4. Measured air change rates at fixed temperature differences across the opening.

The effect of increasing velocities on the air change rate is found if the temperature difference is fixed (see Fig. 4). In the isothermal cases the effect of increasing wind velocity is obvious – higher wind velocity results in higher air change rates, and the curves are close to parallel in this case. When the increase in wind velocity is combined with a temperature difference this effect fades, especially at angles at the leeward side. In the cases where the temperature difference is 5°C these angles span from 135° to 270°, but when the temperature difference is increased to 10°C the spectrum of angles with small or no influence from increased wind velocity is widened to 90° to 270°, which indicates a stronger influence from thermal forces. All cases show that the air change rate is dependent of the wind direction.

3.3 Comparison between measurements and calculations of the volume flow rates

The expressions found by De Gids & Phaff (1) and Warren & Parkins (3) for calculations of the air flow in single-sided natural ventilation are compared to the volume flow rates found from the full scale measurements made in this work, see Fig. 5.

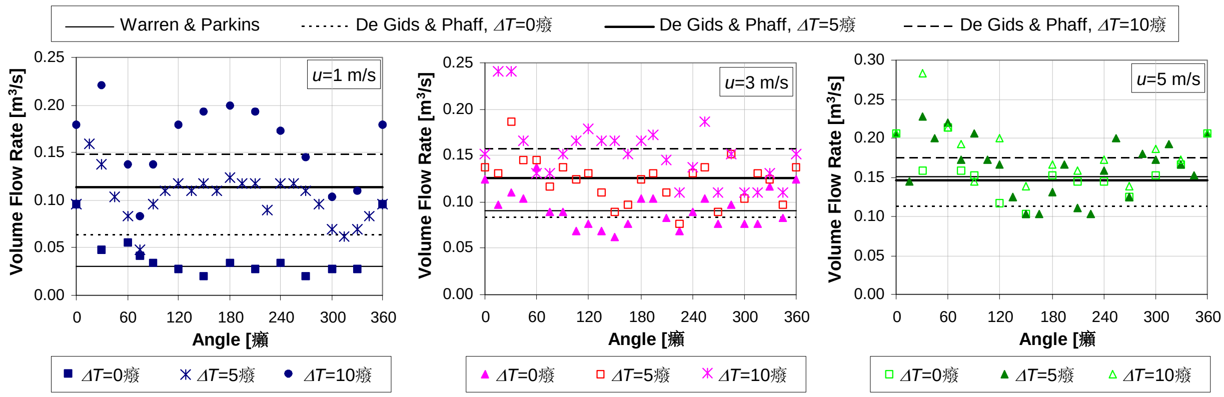

Figure 5. Measured and calculated volume flow rates.

From the comparison of measured and calculated volume flows it is obvious that a new expression needs to be developed to estimate the effect of different wind directions as the present expressions only gives an average indication of the flow rates. Also the importance of the temperature difference across the opening is stressed by looking at the difference between the expressions from Warren & Parkins (isothermal) and De Gids & Phaff.

3.4 Velocity profiles as a function of C_p coefficients

Since the air change rate in a single-sided ventilated room is found to be a function of the wind direction further investigation is necessary to be able to find this relation and later on to be able to calculate the air change rate as a function of the incidence angle.

From measurements of Cp coefficients on the sealed building [2] an average value is calculated at the area where the opening later on is placed. These values are compared to the air change rates at different incidence angles of the wind. Here it is found that the air change rate in cases with low Archimedes number (low temperature difference or high wind velocity) follows the course of the mean value of the Cp coefficients.

From the velocity profiles in the opening (see Fig. 6) it is found that the flow direction at low velocities is much dependent on the temperature difference and in some cases actually change flow direction with increasing temperature difference. With high velocities the profiles are nearly unchanged. The shape of the velocity profiles also changes at both different positions in the opening (not shown at the figure) and at different wind directions. Apparently the reason for this is the variations in the Cp coefficient across the opening area, which affect the velocity distribution in the opening in cases with low temperature differences and/or high velocities. In cases with high temperature difference the flow is dominated by buoyancy, which results in an equally distributed flow across the opening.

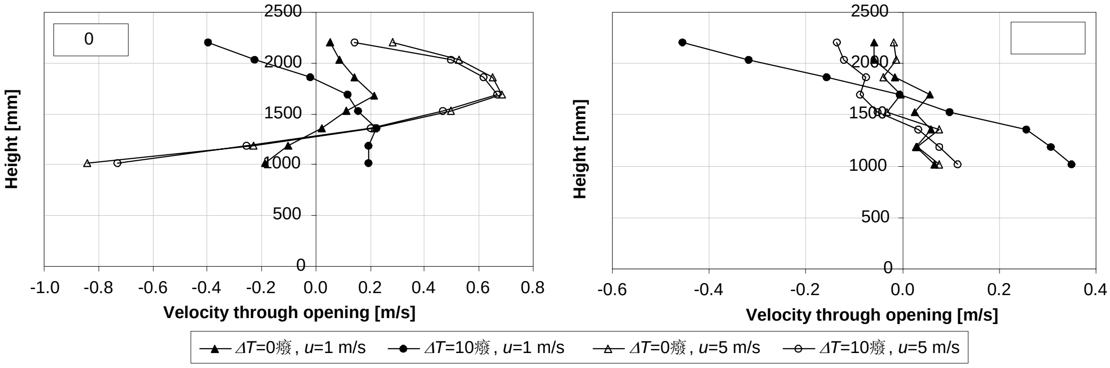

Figure 6. Velocity profiles in the middle of the opening. (Positive values = incoming flows)

4. DISCUSSION

Earlier work (De Gids and Phaff, 1982) has already proven that the air change rate in a single-sided natural ventilated room is dependent on the wind velocity and the temperature difference across the opening. From the results of this work it is found that the air change rate in a single-sided natural ventilated room also is dependent on the wind direction, which is not considered in the present expressions. The main problem for future work is how to find an expression where wind forces, buoyancy forces and incidence angle of the wind all are included. The expression must be able to distinguish between wind dominated and buoyancy dominated cases. Since coherence is found between C_p coefficients and the air change rate and also between C_p variations and the velocity profiles at different incidence angles, an obvious idea is to include these factors in a new expression.

Since it is also found that the size of the Archimedes number affects the pattern of the air flow it might be necessary to divide a new expression into two parts – one for cases dominated mainly by buoyancy and one for cases dominated by wind. This distinction must be made from observations of flow patterns in the experiments.

5. SUMMARY

From results of experiments made in the wind tunnel at BRI it is concluded that the volume flow through the opening in a single-sided ventilated room changes with the wind direction. It is therefore necessary to develop a new expression for calculation of volume flow rates where the variations at different incidence angles are required. The preliminary work for this expression has been presented in this paper and the main idea for further work with the development of the expression will be to include the C_p coefficients from the building envelope.

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REFERENCES

[1] De Gids W, and Phaff H. 1982. Ventilation rates and energy consumption due to open windows: A brief overview of research in the Netherlands. Air infiltration review, 4(1), pp. 4-5

[2] Sawachi T. 2002. Pressure measurements made at test building in wind tunnel. The Japanese Building Research Institute (BRI), Tsukuba.

[3] Warren PR, and Parkins LM. 1985. Single-sided ventilation through open windows. In Conf. Proceedings. Thermal performance of the exterior envelopes of buildings, ASHRAE SP 49, pp. 209-228. Florida.