Laboratory and on-site measurements of natural ventilation rate with solar chimney system

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ABSTRACT

Development of a unique measuring unit for air flow volume within the vertical shaft of natural ventilation system with solar chimney with the results of laboratory test and on-site measurement is presented. As it was considered necessary to make a continuous, simultaneous measurement of a fluctuating air flow within the vertical shafts towards solar chimney, the simple measuring unit was devised. This unit consists of pressure detector and data logger to be installed at several locations. First the relationship between the air velocity and the pressure difference was obtained in the laboratory test. Then this device was installed in several different locations near the grills towards the vertical shafts to measure the pressure difference from which the air flow velocity could be calculated using the relationship obtained from the laboratory test. Based on the pressure difference measured by this device, the air flow velocity at all grilles towards the vertical shafts of a real building having natural ventilation system with solar chimney could be inferred to obtain the air flow rates, where sometimes reverse flow occurs. The results of the on-site measurement agreed quite well with the laboratory test results so that the effects of the natural ventilation system with solar chimney could be estimated. This measuring unit can be used for estimating air flow volume within the underground pit as well.

1. INTRODUCTION

The solar chimney is known as one of the most interesting components for natural ventilation of buildings. The upward air flow is produced by the buoyancy effects from the heated air within the solar chimney which is connected with the vertical shaft as shown in Fig. 1. In this system the outside air is introduced through the underground pit, where the air is to be cooled in the summertime and brought into the occupied spaces of four floors to be taken out to the vertical shaft by the chimney action.

In order to quantify the performance of solar chimney, it is necessary to estimate the air flow rate within solar chimney and underground pit as well as the air flow rate at the open grilles from the corridor to occupied spaces and from the occupied spaces to the vertical shaft.

First we measured the air flow velocity at the grille of all floors to the vertical shaft using hot wire anemometer. With this method it was found impossible to estimate the variable rate of natural ventilation for the spaces of every floor.

Moreover, when natural ventilation takes place, the neutral zone within the vertical shaft

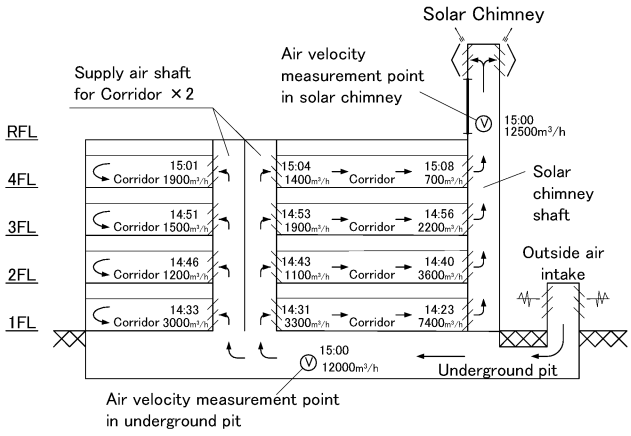

Fig.1 Diagram of natural ventilation system with solar chimney and underground pit with air volume

may change and sometimes reverse flow may occur. It was considered necessary, therefore, to be able to measure the air flow velocity and direction at the grilles continuously and simultaneously in all floors.

Thus the authors devised the measurement system for the purpose of measuring the air flow velocity and direction at the grilles of all floors simultaneously.

This reports the results of laboratory test of this system followed by the field measurement in a real building.

2. SIMPLE TEST MODELS

In order to find out appropriate methods to measure the velocity and direction of air flow at the grilles, two simple test models were fabricated and tested in the real site as shown in

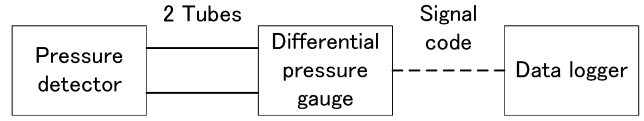

Fig.2 Composition of 1st test model

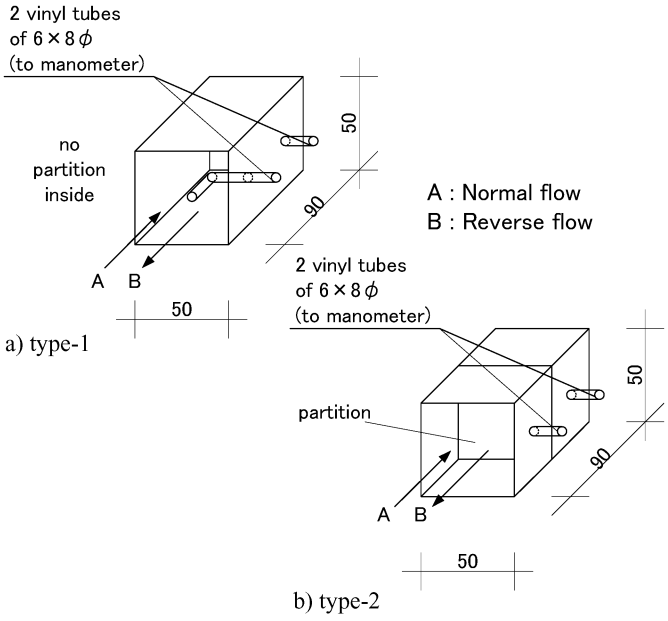

Fig.3 Two types of pressure detector

Fig. 2. This measuring system consists of (1) pressure detector to sense the pressure of 2 points, (2) differential pressure gauge to detect the pressure difference between the 2 points and (3) data logger to record the output signal of the differential pressure gauge. Fig, 3 shows the two types of pressure detector fabricated for this purpose. Fig. 4 shows the examination method with type-1 of the test model.

The experiments were made at the exhaust grille of the fourth floor where reverse flow could possibly occur. The measurements were made at 2 seconds interval. In this experiment the air flow direction was made by eye observation.

The experimental results showed that this measuring method indicated quite accurate values as shown in Fig.5, where the relationships between air velocity and pressure difference were found fairly good with some scattered points. The air velocity will be obtained from the pressure difference in the actual measurements with this measuring system.

Out of two types of test models, type-2 was found more sensitive in the case of reverse flow than type-1.

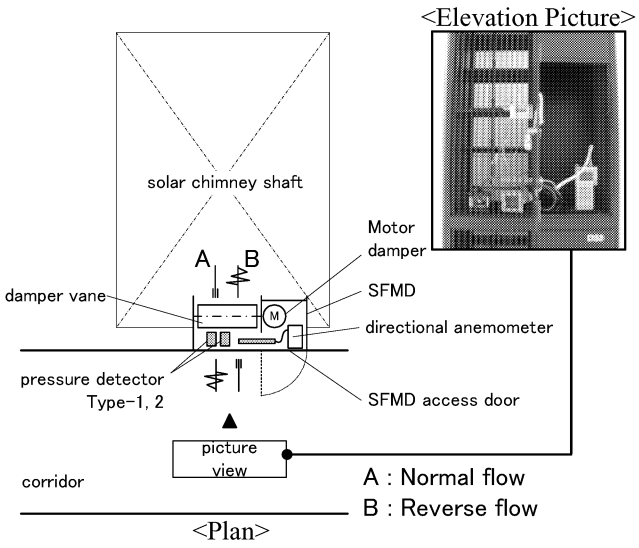

Fig.4 Examination method of 1st test model

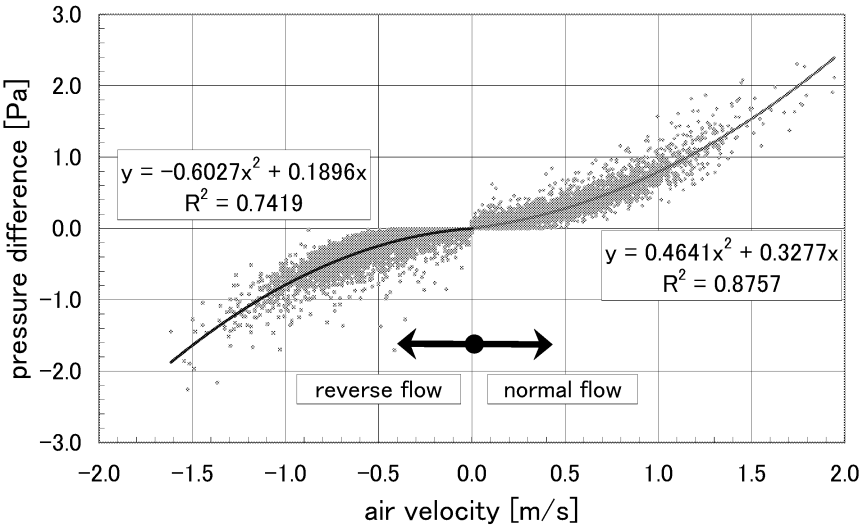

Fig.5 Examination result of 1st test model type-2

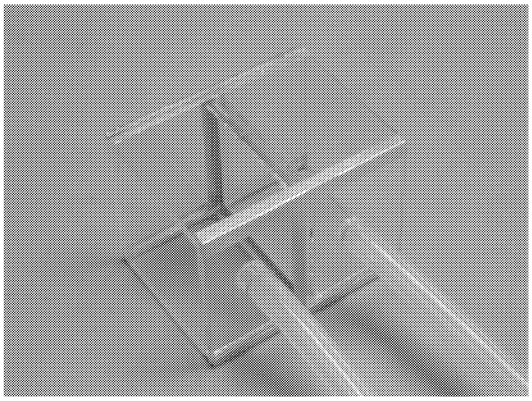

Fig.6 Pressure detector of 2nd test model

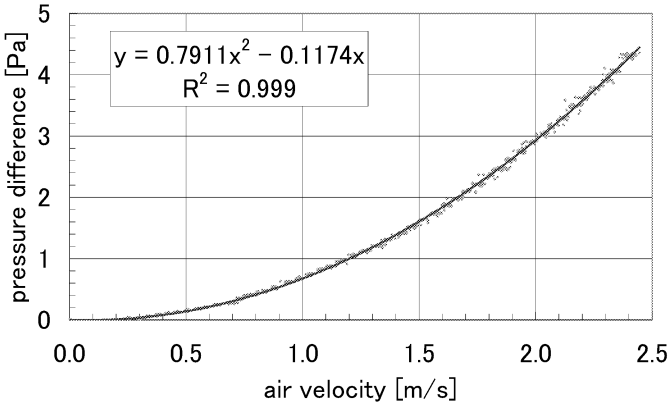

Fig.7 Examination result of 2nd test model in laboratory

3. LABORATORY EXPERIMENT WITH TEST APPARATUS

Based on the simple model test, the pressure detector was fabricated with type-2 of the simple model as shown in Fig. 6. The main body was made with acrylic box connected with silicon tubes.

The laboratory test was made to examine the performance of the pressure detector using a duct type of experimental apparatus. The pressure detector and super-sonic anemometer were set at the open edge 20 cm apart from the end of the duct. With a gradual increase in the rotation number of the fan with inverter, the relationship between pressure difference and air velocity was obtained in the velocity range of 0~2.5 m/s.

Fig.7 shows the results of the laboratory experiment, indicating that the relationship between pressure difference and air flow velocity turned out close to the results of the simple model test, verifying the reproducibility of this method.

4. ON-SITE TEST OF MEASURING UNIT

For the performance verification of the measuring unit in the real situation, on-site measurement was made with hot-wire type of anemometer and the measuring unit in the vertical shaft for supply air of corridor circuit and solar chimney shaft.

Fig. 8 shows the field measurement system flow under the measurement taking place. The measurement was conducted with the pressure detector and hot-wire anemometer installed side by side in the center part of the inside space behind the grille.

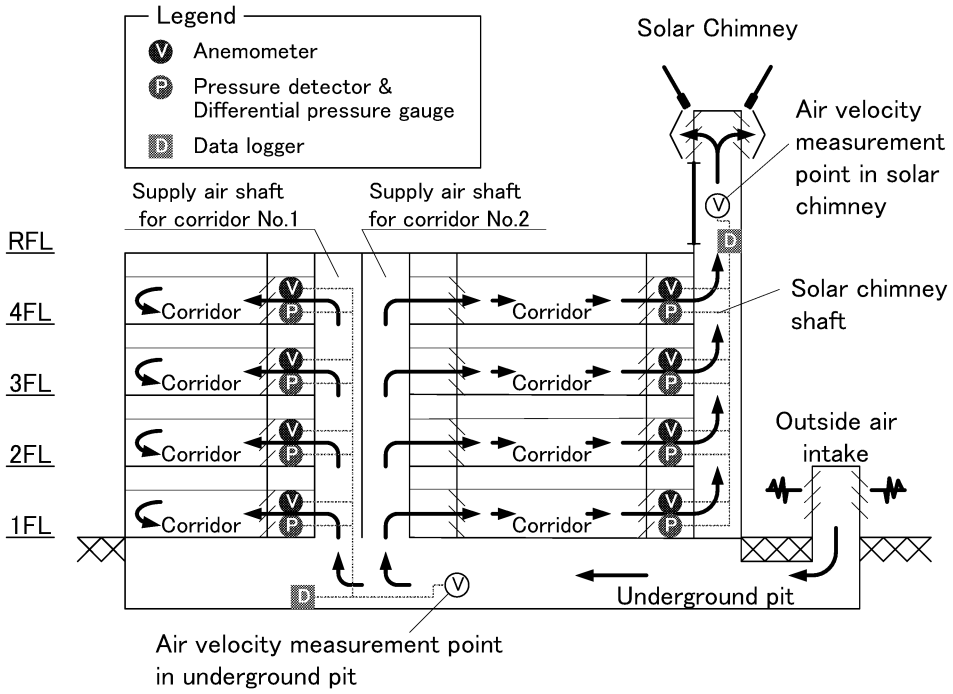

Fig.8 Field measurement system flow

Fig. 9 shows one of the measured results. Compared with the results of the laboratory experiment, some scattering in the data can be found and the reproducibility of the measuring unit could be confirmed.

By making the relationship between the pressure measured by the measuring unit and the air velocity measured by hot-wire anemometer coincided, the pressure record would be converted to the air velocity and air volume afterwards.

Any large discrepancies could not be found in the relationship between the pressure difference Y [Pa] and air velocity X [m/s] from the results of on-site measurement in the supply air shaft of corridor circuit and solar chimney shaft. Then the formulas relating the pressure difference to the air velocity were determined as in the following, viz.,

Normal direction air flow, 0<X, 0<Y:
$Y = 0.8217X^2 + 0.1004X$ ($R^2 = 0.9653$) (1)

Reverse direction air flow, X<0, Y<0:
$Y = -0.7637X^2 + 0,1238X$ ($R^2 = 0.8837$) (2)

5. SUPPLY AIR VOLUME IN VERTICAL SHAFT THROUGH CORRIDOR SPACE

There are two vertical shafts to supply the outside air through the underground pit to the corridor space. The measuring units were installed at a total of 8 grilles in the first to fourth floors to measure the air flow velocity and air flow direction inward and outward simultaneously.

Fig. 10 shows two examples of measured results to indicate nearly the same air velocity at the grilles of the two vertical shafts. It is considered natural, therefore, that the air flow volume through each grille can be obtained as follows:

$$Q = 2vA \quad (3)$$

where:
Q [m^3/s] : air flow volume through each grille
v [m/s] :air flow velocity measured by this measuring unit, converted from pressure difference with equations (1) and (2)
A [m^2] :section area controlled by each measuring point to be multiplied by 2 for upper and lower grilles

Almost no difference was found in air flow volume through the grilles of the two vertical shafts for supply the air to the corridor space.

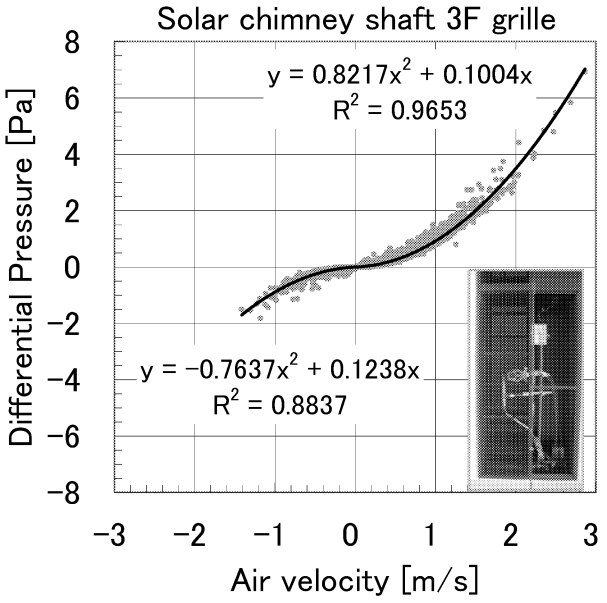

Fig.9 Measurement condition and result of 2nd test model in field

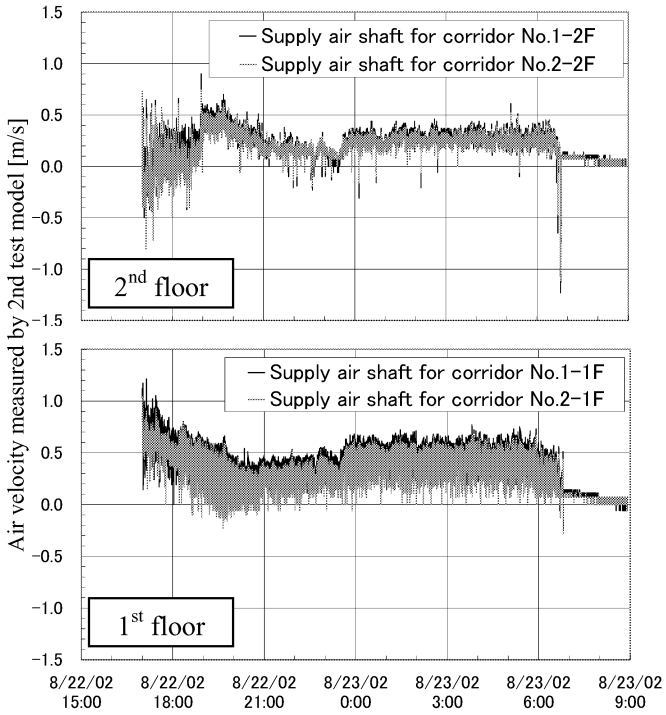

Fig.10 Example of measurement result in two supply air shafts

6. SUPPLY AIR VOLUME FROM VERTICAL SHAFT AND EXHAUST AIR VOLUME TO SOLAR CHIMNEY

In order to estimate the variable air flow volume of natural ventilation, for both supply air and exhaust air, the eight measuring units in total were installed at the grilles of supply air shaft for corridor spaces and solar chimney shaft in the four floors to measure the velocity and direction of inward and outward air flow simultaneously at 2 seconds interval as shown in Fig. 8. Since almost no difference in supply air volumes through the grilles of the two supply air shafts were found as described earlier, the supply air volume at each floor was estimated as twice of the supply air volume for corridor.

Fig. 11 shows some examples of measured results, where <1> the variation of air volumes of natural ventilation for supply and exhaust could be identified, <2> reverse air flow was detected within a part of solar chimney, and <3> supply air volume was found a little greater than exhaust air volume in general, which might have been effected by the operation of exhaust fan for the adjacent office block. The steel doors were closed during the field measurement.

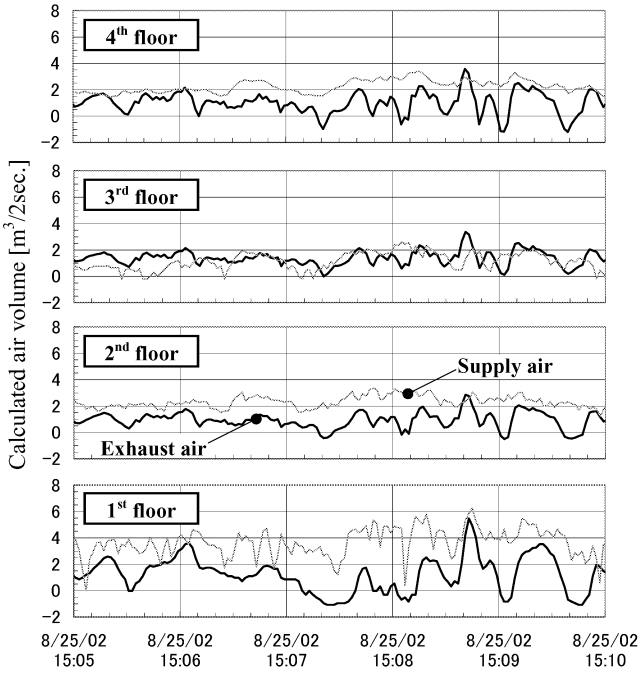

Fig.11 Trend of natural ventilation air volume in each floor

Fig. 12 shows the variations of total exhaust air flow volume from four floors and air flow volume within the solar chimney. It was found that the variations of both air volumes were well coincided with each other in general. A slight

difference can be found between them because of the time difference in the exhaust air flow from the grilles of four floors to the solar chimney.

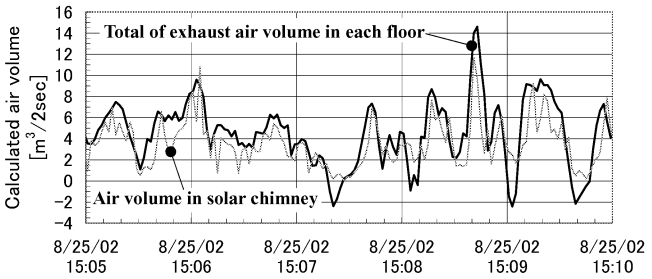

Fig.12 Comparison total of exhaust air volume in each floor with air volume in solar chimney

7. CONCLUSION

An unique measuring unit was developed for measuring the air flow volumes in the natural ventilation system with solar chimney combined with underground pit and tested in laboratory and used for field measurement. The results are summarized as follows.

A simple test model with two types of pressure detector was tested at the grilles on-site and it was found that the type-2 of this system would express the relationship between air flow velocity and direction quite well.

Laboratory experiments were conducted with type-2 pressure detector to identify the relationship between air flow volume and pressure difference. The results showed the relationship turned out nearly the same as those with the simple test model.

This measuring unit was used for on-site measurement. Eight units were installed at the grills of vertical shaft of four floors to measure the pressure difference across the grilles for both inward and outward air flow. The variation of supply air flow through the grilles of supply air shaft and exhaust air flow to the solar chimney could be measured continuously and simultaneously at all grilles of each floor.

Reverse air flow was detected under some occasions.

The total air flow volume exhausted from each floor was found fairly equal to the air volume within the solar chimney.

ACKNOWLEDGEMENT

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