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VENTILATION DESIGN BASED ON THE PROBABILISTIC PREDICTION OF WIND-FORCED VENTILATION RATE —— SPECIFICATION OF NATURAL WIND DATA

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One of the problem in the design method of wind forced ventilation is that it is impossible to grasp the ventilation rate on time series, for the lack of natural wind data. The influence of the difference in the averaging time constant of the data on the relation between the natural wind velocity and the wind pressure on the surface of the enclosure wall which is settled on the roof of a building is investigated. Further, the ventilation rate of the enclosure is measured by tracer-gas method stirring the air inside the enclosure in order to compare with ventilation rate computed from the measured wind pressure. In addition, the ventilation computed from the natural wind data is compared with the measured one. In consequence, it is concluded that it is possible to predict the distribution of relative frequency precisely from the data of wind velocity and direction averaged for 10 minutes.

INTRODUCTION

The design method of wind-forced ventilation (design of ventilating fan, ventilating opening, window etc.) should be based on the prediction of frequency of contaminant concentration and the dose of contaminant to human body. To make such a prediction, the fluctuation of ventilation rate on time series have to be grasped. It is necessary to prepare the various data; meteorological data, wind pressure coefficient, discharge coefficient of the opening and ventilating characteristics of monitor and ventilator if control of ventilation is done. Among the meteorological data, air temperature, humidity and atmospheric pressure are less influenced by time and place in comparison with wind velocity and wind direction. So these data observed and accumulated in the local meteorological observatory can be used in order to estimate the ventilation rate. There have not been easy way to predict the wind pressure coefficient yet. However, by means of wind tunnel test and numerical simulation. It is possible to predict the external wind pressure coefficient for the outer skin of building fairly well. Also, many ventilating characteristics of monitor and ventilator which are used frequently are already presented. Up to the present, it is still difficult to treat the data of wind velocity and wind direction, because these fluctuation are too rapid in time and too different between place. This lack of data makes it impossible to estimate the ventilation rate on time series and to predict the fluctuation speciality.

The authors, therefore, make the following investigation aiming at clarifying the condition of the data enough to make it possible to compute ventilation rate with practical accuracy that is used for ventilation design.

(1) It is investigated how the relation between wind velocity and the pressure on the opening changes with various time constant in each direction classified into 16.

(2) To examine whether it is possible to compute the ventilation rate by equation (1), it is investigated how the relation between the computed ventilation rate obtained from the measured wind pressure and the measured ventilation rate obtained from the tracer gas method changes with various time constant.

(3) To examine whether it is possible to compute the ventilation rate with the practical accuracy that is useful in ventilation design, the computed ventilation rate obtained from the measured natural wind data are compared with the measured ventilation rate.

For these purpose, a cube model which has two openings on opposite sides are settled on the rooftop of an eight-storied building located in the suburb of Osaka, And the natural wind direction and wind velocity above this building, the wind pressure on the openings and air flow rate through the openings are measured daring a long term.

EXPERIMENTAL METHOD

The experiment for the above mentioned purpose is done on the rooftop of a building of Osaka University. The elevation and the roof plan of the building is shown in Fig.1, on which is settled the windmill anemometer and the cube box. The windmill anemometer is settled at about 6 meters above the penthouse of this building. The direction and velocity of natural wind are measured with this windmill anemometer. The cube box is made of the plywood (80*80*80cm). The box has two openings on side walls facing each other. Table 1 shows the conditions of the openings. At the same height as the center line of model and at 1 cm close to the opening, a little hole connected with a tube to measure the wind pressure is opened. The wind pressure is observed as the difference between the pressure at the opening and the standard pressure measured in the wooden box, which has a little infiltration and is settled under the cube box. The data of natural wind velocity, direction and the wind pressure are averaged for 1 minute. The cube box has a small fan for mixing the internal air. The ventilation rate of the box is measured by tracer-gas method. CO_2 is used as tracer. The ventilation rate is computed by substituting the following data into the equation(1); CO_2 concentration before and after 1 minute in the box, CO_2 concentration outside the box, and generation rate of CO_2 inside the box. The continuous data of the natural wind velocity, direction, the wind pressure and the ventilation rate averaged for 1 minute by personal computer are recorded on a 5 inch floppy disk.

RESULT

(1) Relation between the mean wind velocity and the wind pressure

Fig.2 and fig.3 show the relation between the square of mean wind velocity and the wind pressure on the surface of north side wall of the enclosure which are averaged for 1, 10, 30 minutes, in the cases of the wind directions of north and west. The wind direction are classified into 16 directions. The straight line in these figures is the regression line passing through the origin. The reason why the line passing through the origin is adapted is that the wind pressure increase theoretically in proportion to the square of mean wind velocity. Both figures show that the wind pressure are directly proportional to the square of mean wind velocity at any time constant for averaging although the gradient of the regression line is different. This figure also shows that the longer the time constant for averaging is, the better the correlation is, though the gradient does not change according to time constant. As for the other wind direction, the pressure is in direct proportion to the square of mean wind velocity if there is enough the number of data, which are not listed on this paper. The gradient of the regression line, which is proportional to the wind pressure coefficient, changes according to the wind direction.

In Fig.4, the wind pressure coefficient are plotted against wind direction for each time constant. This shows that wind pressure coefficient changes clearly if the wind direction changes and there is little difference caused by the difference of time constant except for the ones of time constant 1 minute.

Fig.5 shows that the deviation from the regression line changes by means of changing time constant on every wind direction. This figure also shows, if the number of the data is enough, the longer the averaging time constant is, the smaller the deviation from regression line is.

From these results, it can be concluded that the longer the averaging time constant is, the better the correlation between the square of mean wind velocity and the wind pressure is. On the other hand, the longer the averaging time constant is, the harder it becomes to estimate the characteristics of fluctuating natural wind and wind pressure. Furthermore, the data of wind velocity and direction observed at meteorological observatory are the averaged value for 10 minutes.

Considering these results and facts, it is proper to use the natural wind data which is averaged for 10 minutes in order to estimate ventilation rate.

(2) Relation between the ventilation rate computed from the measured wind pressure and the measured ventilation rate

Fig.6 shows that the relation between the ventilation rate computed from measured wind pressure data averaged for 1 minute and the measured ventilation rate. There is good correlation between both ventilation rates, although the plots are fairly scattered. The gradient of regression line is 0.77, which means the computed ventilation rate tend to overestimate against the measured ventilation rate. This cause can be considered the result from the error accompanying each estimated value of ventilation efficiency or effective opening area.

Fig.7 shows that the relation between the ventilation rate computed from the measured wind pressure data averaged for 10 minutes and the measured ventilation rate. It is apparent that there is less deviation around regression line than that in Fig.6. The reason of this less correlation in Fig.6 may be that the shorter the time constant for averaging the data is, the greater the influence of time lag for the reaction of CO_2 concentration analyzer and the sampling tube is. The gradient of regression line is constant irrespective of averaging time.

As is mentioned above, Fig.6 and Fig.7 shows that computed ventilation rate is larger than the measured by 30 percent, because the error accompanying each estimated value of ventilation efficiency or effective opening area cause by the turbulent wind blowing at the opening. This is a important problem to be solved in the future, but the authors don't aim at the detailed investigation of this problem in this report.

Although these remain some problems, it can be considered to be possible to predict the ventilation rate precisely using the equation (1).

(3) Relation between the ventilation rate computed from the measured natural wind data and the measured ventilation rate

Fig.8 shows that the relation between the ventilation rate computed from the natural wind data averaged by 10 minute and the measured ventilation rate. The computed ventilation rate in this figure is multiplied for correction by 0.7751 which is the gradient of the regression line in Fig.6 and 7. This figure shows that the measured ventilation rate is almost equal to the computed ventilation rate, though the deviation is a little larger than Fig.7. This some little increase of direction results from the error of the wind pressure coefficient classified into 16 directions.

Fig.9 shows that the comparison between the ogive for computed ventilation rate and the measured one. There is a relatively good agreement of the measured and the computed ventilation rate. The difference of both is less than 5 percent at maximum. From Fig.9 it is concluded that it is possible to predict the relative frequency distribution precisely from the data of wind velocity and direction averaged for 10 minutes.

CONCLUDING REMARKS

(1) It has been made manifest that it is proper to use the natural wind data averaged for 10 minute in order to estimate ventilation rate.
(2) The ventilation rate computed from the measured wind pressure is directly proportional to the measured one, though the computed one is larger than the measured by 30 percent.
(3) The corrected ventilation rate computed from the measured natural wind data is almost equal to the measured one. If only is made clear the reason why the computed ventilation rate is larger than the measured one and this problem is solved, it can be considered to be possible to predict the ventilation rate correctly.

ACKNOWLEDGEMENTS

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Equation (1)

$$Q = 4\alpha A\sqrt{\Delta P}$$

- Q : Ventilation rate
- α : Discharge coefficient
- A : Effective opening area
- ΔP : Difference of air pressure across the opening

Table. 1 The conditions of opening.

	Size of opening (cm)	Discharge coefficient α	Effective opening area αA (cm^2)
North side	60×1	0.64	38.4
South side	60×1	0.68	40.8

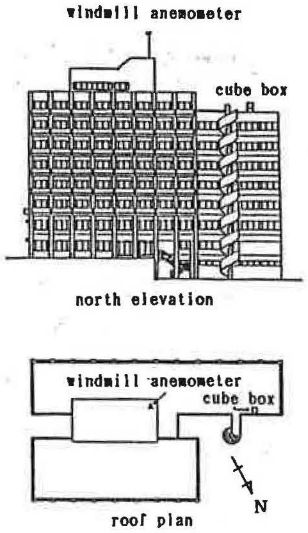

Fig. 1 Elevation and roof plan of the building on which the windmill anemometer and the cube box are settled

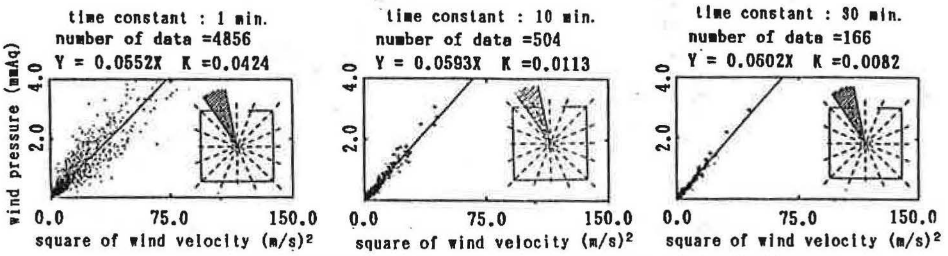

Fig. 2 The wind pressure as a function of square of wind velocity. (wind direction : N)

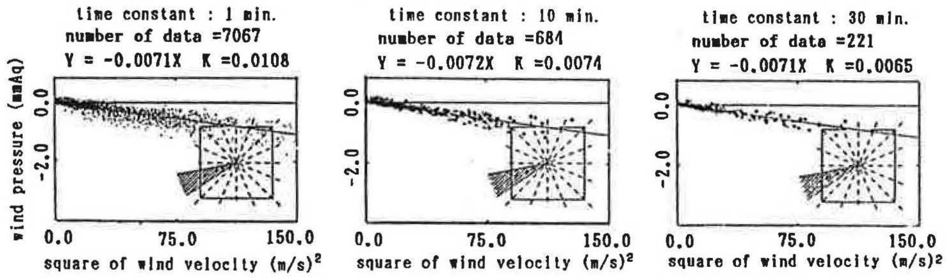

Fig. 3 The wind pressure as a function of square of wind velocity. (wind direction : W)

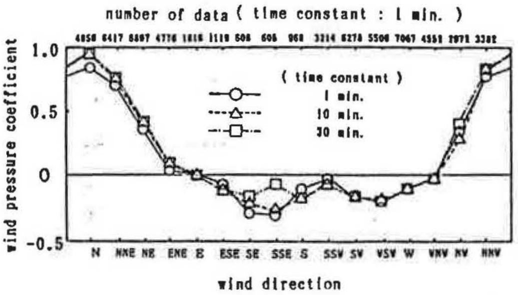

Fig. 4 The wind pressure coefficient as a function of wind direction.

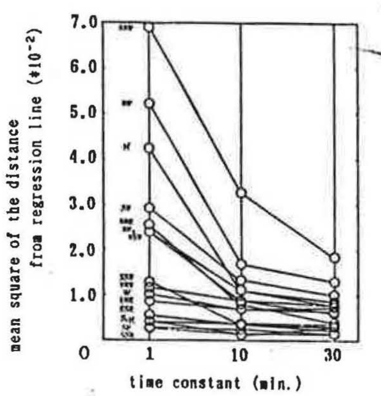

Fig. 5 Mean square of the distance from the regression line plotted against averaging time constant.

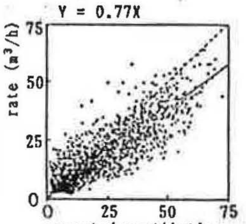

Fig. 6

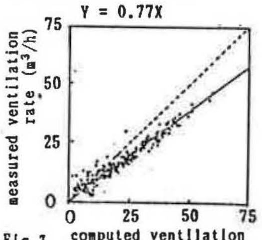

Fig. 7

Fig. 6 The measured ventilation rate as a function of ventilation rate computed from measured wind pressure. (time constant : 1 min.)

Fig. 7 The measured ventilation rate as a function of ventilation rate computed from measured wind pressure. (time constant : 10 min.)

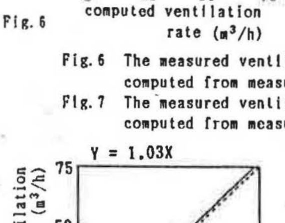

Fig. 8

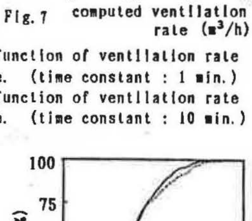

Fig. 9

Fig. 8 The measured ventilation rate as a function of ventilation rate computed from natural wind data. (time constant : 10 min.)

Fig. 9 Ogive for ventilation rate (time constant : 10 min.)