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VENTILATION EFFICIENCY IN THE ROOM WITH A SINGLE OPENING

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ABSTRACT

The aim of this study is to propose a new ventilation efficiency suitable for natural ventilation design and to investigate the characteristics of air flow inside the room with one opening and make the ventilation efficiency clear.

As the mechanism of single-openinged ventilation is known to be pulsation and wind pressure distribution by eddy, the ideal air flows according to these two mechanisms are made at the single opening of model enclosure to examine the independent ventilation efficiency under each mechanism. The time decay of the concentration of CO_2 as a tracer gas is measured after filling the enclosure with CO_2. It is tried to account for ventilation efficiency by the air velocity through opening. In addition, the ventilation efficiency is tried to explain by two types of flow model.

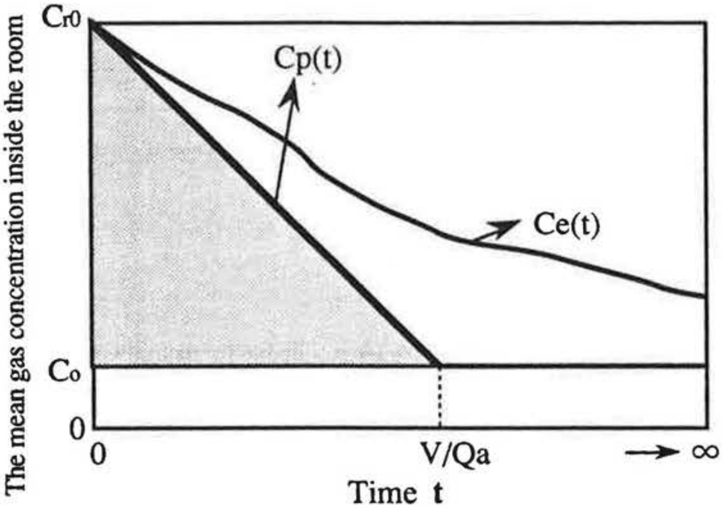
KEYWORDS Single-openinged Ventilation, Ventilation Efficiency, Pulsation, Penetration of eddies

INTRODUCTION

The room should have more than two openings in view of natural ventilation. There are, however, many cases that a room has only one opening or only one opening is opened. It is known that such a room is ventilated to some extent due to the turbulence of natural wind, but the ventilation effectiveness and contaminant distribution in the room is not known enough.

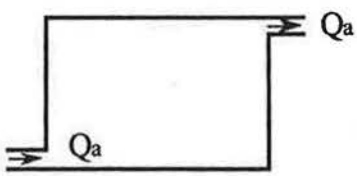
On the other hand, there are few definitions of ventilation efficiency that are suitable for the natural ventilation design, although many ventilation efficiencies have been defined by many people. (Constance 1970, Jennings and Armstrong 1971, Drivas et al. 1972, Kusuda 1976, Sandberg 1981, Murakami and Katow 1986 etc...)

As the mechanism of single-openinged ventilation is known to be pulsation and wind pressure distribution by eddy(Malinowski 1971), the ideal air flows according to these two mechanisms are made at the single opening of model enclosure to examine the independent ventilation efficiency under each mechanism. The relationship between the air velocity through opening and ventilation efficiency are examined. In this paper, a new definition of ventilation efficiency which is suitable for natural ventilation design is introduced and the ventilation effectiveness of one-openinged ventilation is examined using the new ventilation efficiency. In addition, in order to account for the ventilation efficiency the flow models are presented.



$$C_p = C_{r0} - \frac{Q_a}{V}(C_{r0} - C_o)t \quad (0 \leqq t \leqq 1)$$

$$\eta = \frac{S_1}{S_2} = \frac{\int_0^{\frac{V}{Q_a}} (C_p - C_o)dt}{\int_0^{\infty} (C_e - C_o)dt}$$



here, $S_1 = \frac{1}{2} \times \frac{V}{Q_a}(C_{r0} - C_o)$

If the decay of gas concentration obey the exponential function,

$$C_e = C_o + (C_{r0} - C_o)e^{-\frac{Q_e}{V}t}$$

$$S_2 = \int_0^{\infty} \{(C_{r0} - C_o)\, e^{-\frac{Q_e}{V}t}\} dt = \frac{V}{Q_e}(C_{r0} - C_o)$$

therefore, $\eta = \frac{S_2}{S_1} = \frac{Q_e}{2Q_a} = \frac{1}{2}k$

Fig.1 The Definition of Ventilation Efficiency

NOMANCLATURE

- C_{r0}:the mean gas concentration inside the room at t=0
- C_o:the gas concentration of supply air
- C_p:the predicted mean concentration in the case of displacement ventilation
- C_e:the mean gas concentration inside the room
- V:the total volume of the room
- k:mixing factor ($=Q_e/Q_a$)
- S_1:the area of ▇
- S_2:the total area of ▇ and ☐
- Q_a:air flow rate through the opening
- Q_e:the ventilation rate

DEFINITION OF NEW VENTILATION EFFICIENCY

The new ventilation efficiency is defined by the area under the decay curve of tracer gas inside the room. The decreasing gas concentration technique of tracer gas is needed to measure this ventilation efficiency. As is shown in Fig.1, the ventilation efficiency is the ratio of the area under the curve in the case of perfect piston flow to the area under the curve of measured mean concentration of tracer gas inside the room. This ventilation efficiency is to be 0.5 if the inside air condition is perfect mixing and to be 1 in the case of piston flow(displacement ventilation). Any ventilation system has the value ranging from 0 to 1. It is necessary to integrate the decay curve when you are going to calculate the ventilation efficiency. If, however, the concentration decay obey the exponential function, the ratio of ventilation rate to air flow rate through the opening is equal to the ventilation efficiency. This value correspond to the half of mixing factor. The transformation of equations is listed on Fig.1.

SIMULTANEOUS INFLOW AND OUTFLOW THROUGH SINGLE OPENING

To simulate the symplified flow of eddy penetration at the opening, the forced inflow and outflow through an single opening are made. Fig.2 shows experimental apparatus. The air is supplied through an single opening by circular alminum pipe set in front of the opening. The air is forced to flow out through the rest portion of the same opening. The model enclosure has small mixing fan. CO_2 gas is used as a tracer gas. To measure the mean CO_2 concentration in the room, the initial mean concentration and ultimate mean concerntration after a certain time interval are measured mixing the inside air by small fans. The time intervals are the time enough for the concentration to decrease to 3/4 of initial concentration. The experimental conditions are listed in Table 1.

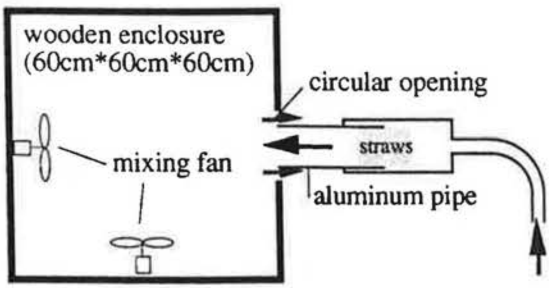


Fig.2 Experimental apparatus

Table 1 Conditions of experimental parameters

diameter of Circular opening(mm)	diamter of circular alminum pipe(mm)	flow rate(L/min.)
40	5,10,15,20,30	1,3,5
20	5,10,15	1,3,5

The ventilation efficiency is calculated by the supplied air flow rate and measured ventilation rate. The obtained ventilation efficiencies are shown in Fig.3 as a function of the ratio of outflow velocity to inflow velocity at the opening. This figure

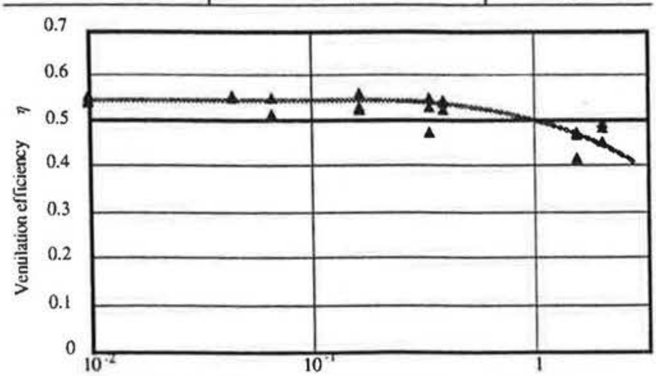


Fig. 3 The relationship between the ratio of outflow velocity to inflow velocity and the ventilation efficiency

show that the ventilation efficiency can be more than that of perfect mixing if the inflow velocity is larger than the outflow velocity. On the contrary, the ventilation efficiency get worse than perfect mixing if the inflow velocity is slower than outflow velocity.

It is considered to be possible to apply this kind of ventilation to the air conditioning system in buildings.

PULSATING FLOW THROUGH SINGLE OPENING

To make the ideal pulsation flow at the single opening, the experimental apparatus as is shown in Fig.4 is made. The pulsating flow are made by varying the the volume of the model enclosure periodically. The volume and frequency of pulsation can be changed. The ventilation rate is measured by tracer gas technique with CO_2 in the same way as above-mentioned experiment.

At first, the model enclosure is filled with CO_2 and the mean concentration is measured. Then the motor is turned on to make pulsating ventilation. After some time enough for stable ventilation rate, the mean CO_2 concentration is measured so that the ventilation rate is calculated.

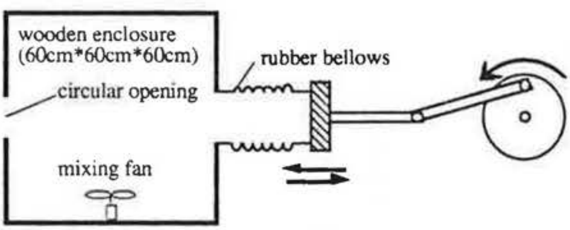


Fig.4 Experimental apparatus

The experimental conditions of some parameters are shown in Table 2.

Table 2 Conditions of experimental parameters

frequency of Pulsation (Hz)	1,2,3
diameter of circular opening.(mm)	20,40,60
volume of fluctuation (cm3)	16.1, 21.9, 42.4

As the periodical change of the enclosure volume obeys sine-function, the theoretical velocity at the opening can be calculated. Root mean square of velocity variation is obtained theoretically, which could be considered to be representative of the fluctuating velocity. In fig.5, the ventilation efficiencies are plotted against the R.M.S. of air velocity through the single opening. Although the correlation between them is not so good as Fig.3, there is positive correlation in each fluctuating frequency. The higher the R.M.S. of velocity the higher the ventilation efficiency. At the same R.M.S. of velocity, the lower the frequency the higher the ventilation efficiency. In some cases, the ventilation efficiency is more than that of perfect mixing (0.5). The widespread distribution of data indicate the

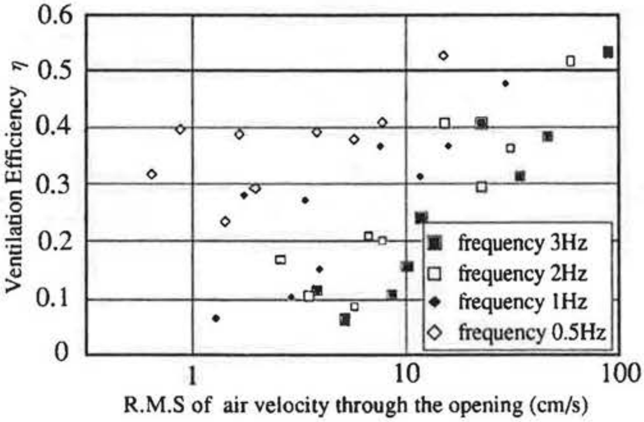


Fig. 5 The relationship between R.M.S. of air velocity through the opening and ventilation efficiency

there are some other factors that determine the ventilation efficiency other than R.M.S. of velocity.

DISCUSSION

In this paragraph, we would like to discuss the reason of the tendency in Fig.3 and Fig.5. It turned out that the ventilation efficiency is much affected by the velocity through the single opening. That is, in both cases of pulsation and steady flow, the higher the velocity the better the ventilation efficiency. This tendency can be explained by following two types of two zone flow ; one is displacement flow model (piston flow model) and the other is short-circuit flow model. These models are illustrated by Fig.6. The difference of these models is the zone that the air flow out of through an opening. In both models, there are mutural air flows coupling two zones. When the velocity through the opening is low, the air could not reach the interior of enclosure so that the air is exhausted before being mixed with inside air. In this case case, the short-circuit model is applicable. When the velocity is high eough to reach the interior, the displacement model is applicable.

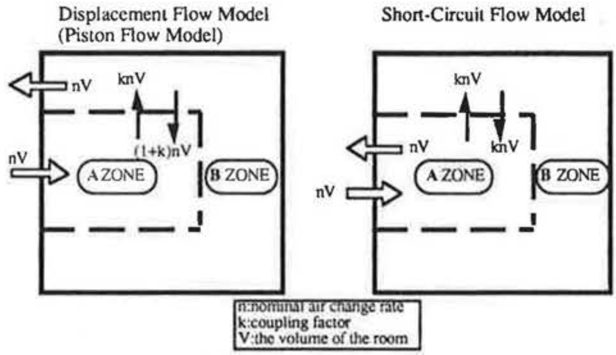


Fig.6 Two types of two zone model

To examine these models, the decay of gas concentration in each zone and mean concentration in the room are calculated and illustrated in Fig7 and 8. The parameters are set as follows; the volume of each zone is the same, the volume of the enclosure is the same as the experiment, air change rate n is 1.095, k=2. The straight line in these figures is the concentration decay in the case of perfect mixing and the alternate

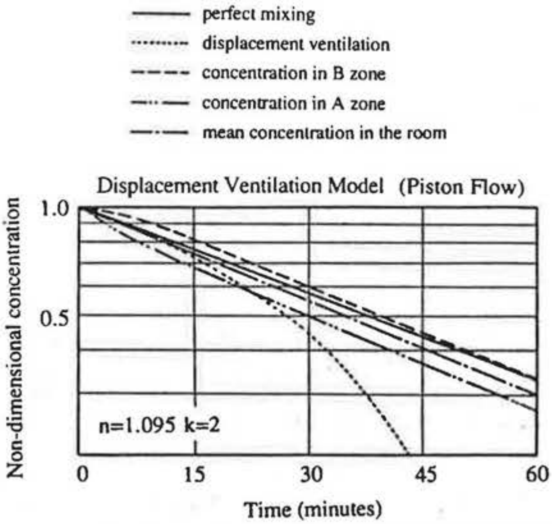


Fig.7 Concentration decay of each zone by displacement flow model

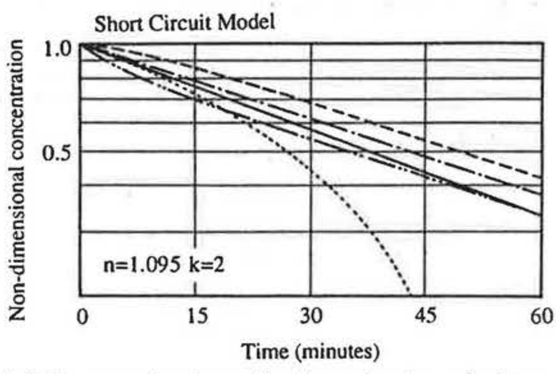


Fig.8 Concentration decay of each zone by short- circuit model

long and short dash line is the mean concentration in the room. Comparing these two lines in each figure, it can be seen that the ventilation efficiency of displacement ventilation is better than perfect mixing but that of short circuit flow is less than perfect mixing. These figures show the applicability of two models to account for the influence of the opening velocity on the ventilation efficiency. Though the figures are not listed on this paper, the similar figures are gotten by the measurement of concentration inside the enclosure under pulsating flow.

CONCLUSIONS

The representative results are as follows.

1.The ventilation efficiency defined in this study can be applied to express the difference of ventilation efficiency inside the model enclosure with a single opening.

2.In the case of the steady flow through a single opening, the ventilation efficiency in the enclosure is better than that of perfect mixing if the velocity of inflow is larger than the velocity of outflow through the opening. On the contrary, the ventilation efficiency become worse than that of perfect mixing if the outflow velocity is larger than inflow velocity.

3.In the case of the pulsating flow at single opening, there is a positive correlation between the R.M.S. of the air velocity through the single opening and the ventilation efficiency, but the higher the frequency of pulsation the lower the ventilation efficiency.

4.The qualitative tendency of ventilation efficiency can be accounted for by two zone air flow model.

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