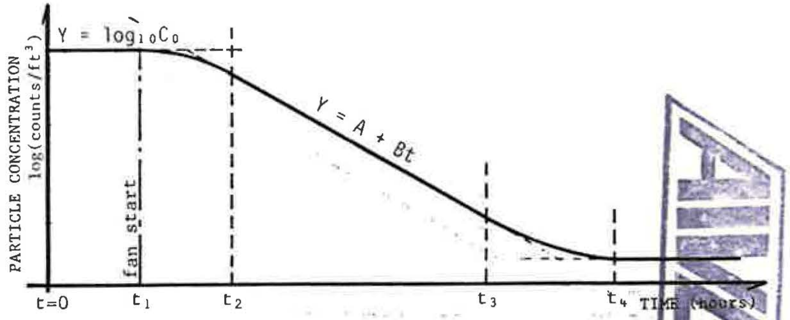
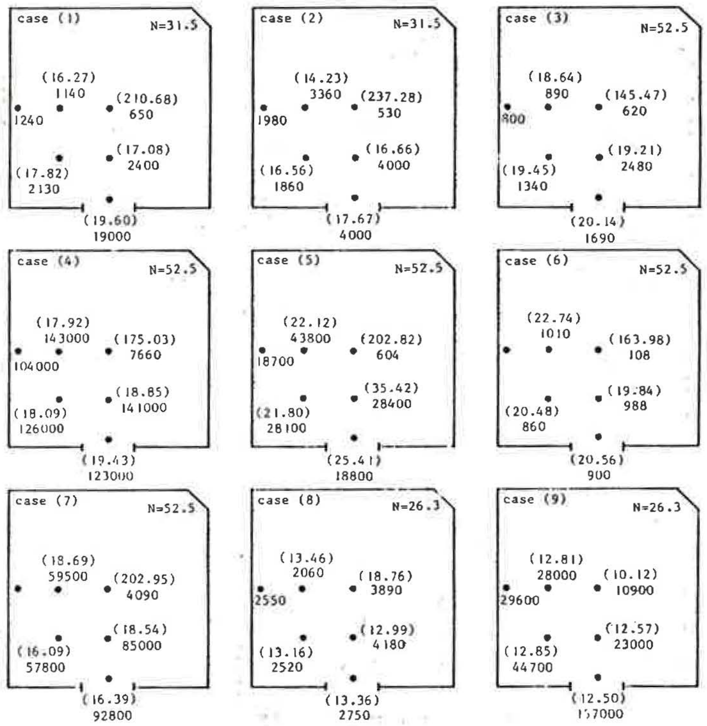


Fig. 3: Schematic diagram for the change of particle counts along time



(xxx) : potential number of air change
xxx : particle concentration
N : damping factor in Eq.(2)

Fig. 4: Particle concentration (≥0.3μm) and potential number of air change

INFLUENCE OF TURBULENT WIND ON VENTILATION

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Abstract

One of the problems in the design method of wind forced ventilation is that the influence of turbulent wind on ventilation is not taken into account. The most notable example is that the ventilation rate of a room with a single opening subjected to turbulent wind can not be predicted. The need to establish the design method allowing for the turbulence of wind is stated and its conceptional flow chart is presented. The air flow rates through a single opening of model enclosure subjected to artificial wind are measured by tracer-gas method stirring the air inside the enclosure in order to investigate the effect of various factors (mean air velocity, turbulent intensity, opening area, incident angle of wind) upon the air flow rate. In addition, the air flow rates computed with the theoretical model of pulsation are compared with the measured values.

Introduction

The theory of wind forced ventilation based on the steady pressure generated by wind has been already established, but the design method using this theory has the following two defects.

1. It is impossible to predict the fluctuating wind pressure distribution on an opening caused by turbulent flow, which makes it difficult to estimate the air flow rate through openings correctly. For instance, it is impossible to calculate the ventilation rate of a room with only a single opening exposed to wind, although it has been confirmed that such a room is ventilated to some extent.(1,3,4) That holds good for a room with several openings exposed to the same mean wind pressure.(2,5)
2. Generally perfect mixing of the contaminant and the air in a room is often assumed to compute ventilation requirements. Actually, however, the uneven distribution of contaminant concentration will arise in the room and concentration of some points can exceed the allowable level of contamination.

We, therefore, aim at setting up more reasonable and practical method of wind forced ventilation design whose conceptional flow chart is shown in Fig.1. Though each item is still conceptional in this figure, the characteristics of turbulent wind are included in "Factor of Natural Wind" and the air flow rate through an opening is regarded as the main numerical value in "Conditions of Air Flow Through Opening". Among many problems to examine for the purpose of establishing this method, the influence of turbulent wind on ventilation will be investigated in this paper. As an object of this study, ventilation of a room with a single opening is taken up. Experiments on a model enclosure are conducted in order to investigate the effect which various factors (mean air velocity, turbulent intensity, opening area of circular opening, incident angle of wind) have on the air flow rate through an opening. For it seems to be difficult to calculate air flow rate from the data of velocity distribution on the opening, the volume of enclosure multiplied by the air change rate derived from tracer-gas method stirring up air inside the enclosure is considered to be equivalent to the air flow rate through an opening. In addition, the air flow rates are computed by the theoretical model of pulsation, then the computed air flow rates will be compared with the measured air flow rates so as to examine the possibility of estimating air flow rate using the theoretical model.

Experimental Method

As is shown in Fig.2, the equipment for experiment consists of a cube enclosure with dimensions 0.6×0.6×0.6m and a fan with a duct of 2.5m long and 0.4m in diameter. The enclosure has a single opening installed at the center of the face to windward. Three types of artificial wind with different turbulent intensities are used. These winds are made through honneycombs of different sizes at outlet of the duct. As the air inside the enclosure is continuously stirred up by the equipment shown in Fig.3, the decay of CO_2 concentration is measured to calculate the air change rate with equation by Seidel. Air velocity of unobstructed wind is measured with an anemometer and its signal is recorded by the cassette tape data recorder.

Varied parameters are followed.

Table 1: Conditions of varied parameters

Air velocity (m/s)	1.0	2.0	4.0	2.0						
Type of wind (turbulent intensity)	I (high)	II (medium)	III (low)	I	II	III				
Diameter of opening (mm)	20	28.3	40	40						
Incident angle of wind (deg)		0		0	15	30	45	60	75	90

Theoretical Model of Pulsation

The process of air exchange at the single opening has been considered as a resultant of the pulsation and the penetration of eddies.(4) If an even distribution of wind pressure on an opening could be assumed, only pulsating flow occurs on account of fluctuating wind pressure and the following equations are derived. These are identical with the fundamental forms of equations by J.P.Cockroft and P.Robertson.(1)

$$Q_c = \int_0^T q_i\,dt / T = \int_0^T q_o\,dt / T$$

$$q_i = 4\,\alpha A \sqrt{P_o - P_i} \qquad (P_o \geqq P_i)$$

$$q_o = 4\,\alpha A \sqrt{P_i - P_o} \qquad (P_o < P_i)$$

$$P_i \cdot \{V - \int_0^t (q_i - q_o)\,dt\}^{\gamma} = P_{io} \cdot V^{\gamma}$$

$$P_o = C \cdot U^2 / 16 + P_a$$

Q_c : computed air flow rate (m^3/s)
q_i : inflow rate (m^3/s)
q_o : outflow rate (m^3/s)
αA : effective opening area (m^2)
P_o : external pressure (mmAq)
P_i : inside pressure (mmAq)
V : enclosure volume (m^2)
γ : ratio of specific heats of air (=1.4)
P_{io} : initial pressure inside enclosure (mmAq)
C : wind pressure coefficient (=1.0)
U : air velocity ($\bar{U} + u$) (m/s)
P_a : atmospheric pressure (=10333 mmAq)

The recorded signal of air velocity U is converted into digital values with a time interval of 0.1 ms and the in- and outflow rate can be calculated continuously with computer. The average air flow rate for 20 seconds is derived for each condition. (only for incident angle θ =0)
To investigate the effect of frequency characteristics of velocity variation on air flow rate, the frequency components of air velocity are cut off by averaging for different time constants.

Results

Fig.4 shows the relation between the mean air velocity and the air flow rate. This shows that air flow rate increase in direct proportion to mean air velocity for each wind type and opening.

Fig.5 shows the relation between the opening area and the air flow rate. Both are almost in direct proportion for each mean air velocity and wind type.

Fig.6 show the relation between the turbulent intensity and the air flow rate on full logarithmic axes. It is demonstrated that the air flow rate tends to be in proportion to the half power of turbulent intensity for each mean air velocity and opening.

Fig.7 shows the air flow rate plotted against the incident angle of wind for each wind type and the opening ϕ 40. The curve of each wind type has a evident peak at the angle of 75 degree. At all the angles, the greater the turbulent intensity is, the higher the air flow rate becomes.

The tendency in Fig.3,4,5 suggest that the product of mean air velocity, opening area and the half power of turbulent intensity is in proportional to the air flow rate. Fig.8 proves that this supposition is right. The simple theoretical equation by Cockloft et al. overestimates the air flow rate. (calculated / measured = 10.8)

Fig.9 show the relation between the computed air flow rate and measured air flow rate. There is a good correlation between them, and computed values from high-cut filtered data of air velocity have a better agreement than the ones from non-filtered. It is because filtering can omit the high frequency component of air velocity that cause the inflow to flow out without being mixed.

So far as the incident angle is zero, the theoretical model of pulsation is very useful. But it is only wind pressure coefficient C that can take into accout the effect of incident angle in this model and the coefficient C is usually largest at the angle of zero. So it is evident from Fig.7 that this model does not estimate the effect of incident angle correctly. When the incident angle is away from zero, the penetration of eddies will dominate in place of pulsation. To predict air flow rate in the case that the incident angle is not zero, it is desirable that more realistic and applicable theoretical model should be made.

Conclusions

It has been made manifest that the air flow rate through an single opening is in proportion to mean air velocity, opening area and the half power of turbulent intensity and becomes largest at the incident angle of 75°. Computed air flow rate with theoretical model of pulsation could estimate the measured air flow rate using the filtered data of velocity on condition that the incident angle equals zero. This model, however, turned out to be little applicable in the case that the incident angle is away from zero, so that the more realistic model taking account of the penetration of eddies should be built up for comprehensive application.

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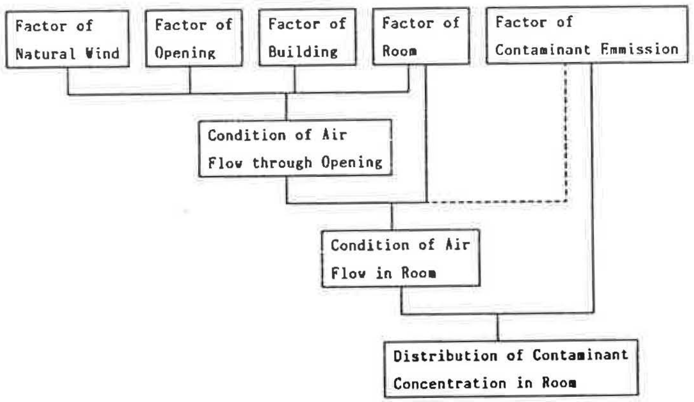
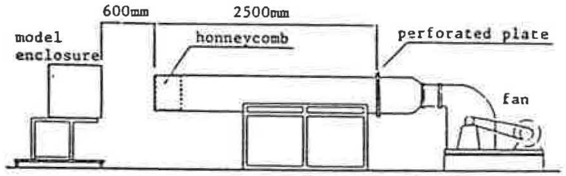


Fig.1 The conceptional flow chart of wind forced ventilation.



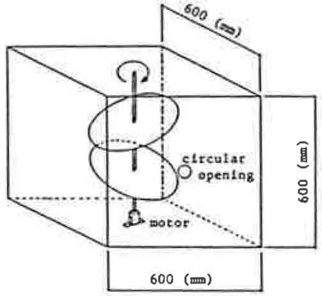
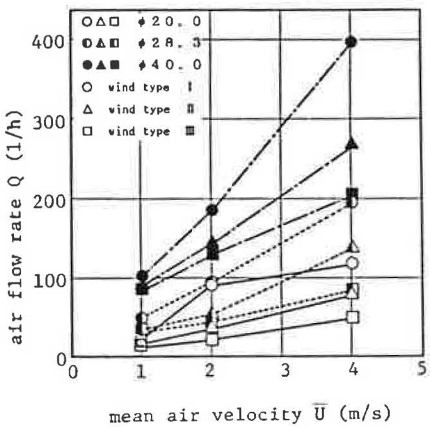


Fig.2 The equipment for experiment.

Fig.3 A model enclosure and stirring equipment.



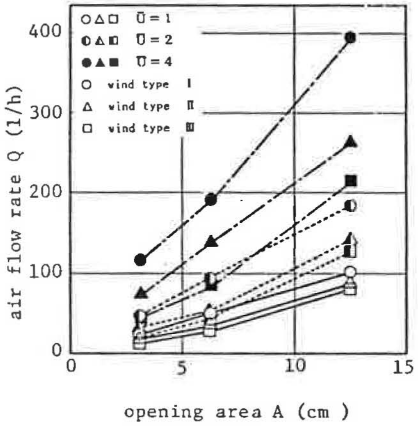
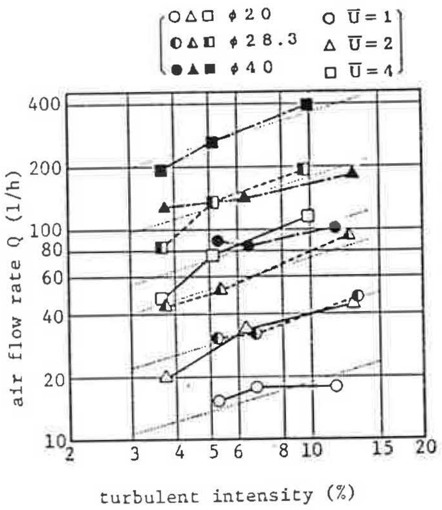


Fig.4 The measured air flow rate as a function of mean air velocity. (the incident angle =0)

Fig.5 The measured air flow rate as a function of opening area. (the incident angle =0)



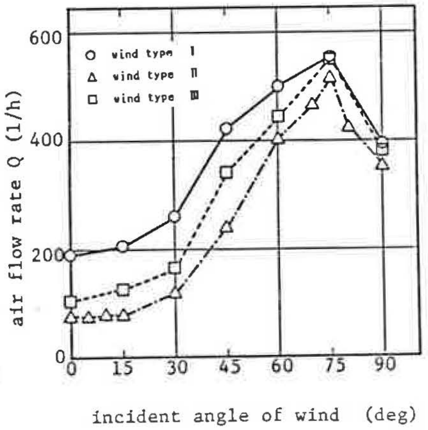
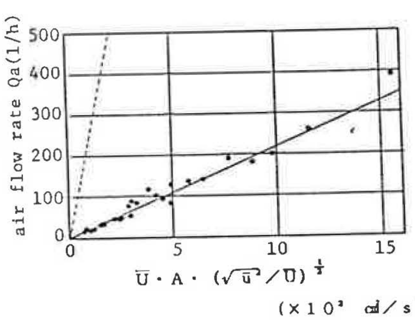


Fig.6 The measured air flow rate as a function of turbulent intensity on full logarithmic axes. (the incident angle =0)

Fig.7 The measured air flow rate as a function of incident angle of wind.



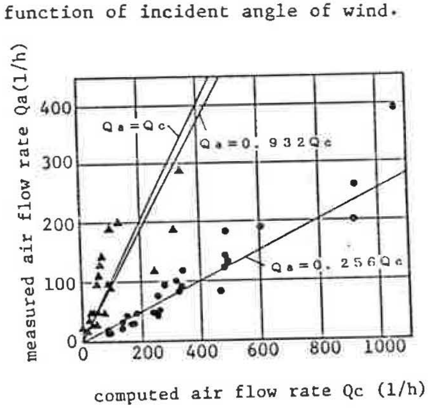


Fig.8 The measured air flow rate as a function of the product of mean air velocity, opening area and the half power of turbulent intensity. The simple equation by Cockroft et al. is drawn in a broken line.

Fig.9 The comparison between the measured air flow rate and computed flow rate. ●:from the non-filtered data of air velocity ▲:from the high-cut filtered (over 100Hz)data of air velocity.

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EVALUATION OF LOW-COST TRACER TECHNIQUES FOR MEASURING AIR EXCHANGE RATES IN BUILDINGS

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Abstract

The aim of this study was to find and evaluate a simple detector or method for routine air exchange rate measurements in dwellings and office buildings. The experimental work was mainly focused on evaluating a semiconductor sensor for the detection of freon 12 (dichlorodifluoromethane). The applicability of carbon dioxide indicator tubes for air exchange measurements, CO_2 as a tracer gas, was also studied. It was found that these methods can be used only when an approximation is sufficient.

Introduction

A common method for measuring air exchange rate or air infiltration characteristics in dwellings and office buildings uses the dilution of a tracer gas. In this method a small quantity of a tracer gas is introduced into the room, mixed homogeneously, and the concentration of the tracer gas versus time is recorded. The concentration of the tracer gas is usually measured with sophisticated instrumentation. Two approaches for tracer gas monitoring are in general use. The sampling tubing is installed in the building and the concentration is analyzed continuously or at certain time intervals with an IR analyzer, electron capture detector gas chromatograph or a portable masspectrograph (2, 3, 4, 6). Another technique is based on spot sampling and later analysis in the laboratory (1, 5). In both cases skilled analyzers and operators are needed.

Because the tracer gas technique is widely used in air exchange measurements, there is a current need to develop simple and inexpensive detectors for tracer gas monitoring. The aim of this study was to find and evaluate a simple detector or method for routine air exchange rate measurements in dwellings and office buildings. The experimental work mainly focused on evaluating a semiconductor sensor (TGS, Figaro Engineering Inc.) for the detection of freon 12 (dichlorodifluoromethane). The applicability of carbon dioxide indicator tubes for air exchange measurements, CO_2 as a tracer gas, was also studied.

Methods

The gas sensitive semiconductor TGS sensor is based on the n-type sintered SnO_2. The detector contains a heating coil and a gas detecting element. When combustible or toxic gases