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STUDY ON CHANGE FROM SUMMER ORIENTED HOUSES TO WINTER-ORIENTED ONES AND THEIR VENTILATION

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Abstact

A traditional Japanese wooden house has many path ways for ventilation to exhaust the moisture and to preserve the wooden construction. In Hokkaido with cold winter, airtightening is a necessary change and much improvement has been tried to the present. The degrees of airtightness in several kinds of constructions are shown in this report. Though the vapor condensation in cold rooms become more serious in an airtightend house, more insulation and airtightening are necessary when we desire to change the custom of partial warming to a whole house heating system. Natural ventilation by fluctuating wind was studied for the accurate calculation of ventilation and for the vapor exclusion from the exterial wooden wall having thick insulation. The design of ventilation routes in an airtightened house is important for health and heating economy. The authors show the designing principle and the measuring method of exchanging ventilation in a multi room house by using multi－tracer gases.

1. Preface

Traditional Japanese houses were made mainly of wood, straw, mud and paper. It had been said that the house should be made with an emphasis to make it comfortable to live in summer.

In a climate with humidity and high temperature at "Tsuyu" period which is the rainy season in early summer brought by monsoons from the southeast sea, an exhaustive ventilation throughout the house is required for not only cooling but for the preservation of building material itself.

The buffer spaces in a house such as attics or crawls are opened completely to the outside and wooden walls which have cavities inside are also opened to these buffer spaces. The ceilings and floors have also numerous planned cracks to lead to a natural ventilation in a house. This is a special feature of a Japanese traditional house, in which all spaces are closely connected with each other by complicated ventilation routes resembling a net work.

Department of Architecture

Naturally it was difficult to keep the temperature in a house constant in winter, so our forefathers took warmth directly from an open hearth fire such as "Irori", closed "Kotatsu" or later a heater. Thus the partial and intermittent heating had become a deep routed custom in Japan. These traditional houses and customs were also brought to Hokkaido by the early settlers.

Although the airtighting of the house was an inevitable fact for the reduction of cold draught, freezing of water and fuel consumption, vapour condensation in cold rooms has become serious problem. As the solution, thicker insulation and increased airtightness are definitely necessary to change the custom of partial heating into whole house heating. These studies on ventilation have been made with such backgrounds. The aim of these studies is not to reduce the amount of ventilation but to keep the effective ventilation under the fluctuating wind pressure and its positive use for the preservation of wood constructions with thick insulation.

2. Airtightness of Japanese Houses

Though the Japanese houses have taken an a semi western style, especially in Hokkaido, the degree of airtightness is not yet so high because of their traditional post and beam wooden frame construction. They have many cracks and path ways of air in the wall, so the quantity of ventilation is also large. As the superfluous ventilation brings bitter cold draught and large heat loss, constractors in Hokkaido are making a great effort to improve this problem.

To know the degree of airtightness of new type houses in Hokkaido, the authors have measured the equivalent leakage area by the depressurization method as shown in fig.1.

The equivalent leakage area αA is obtained by following equation.

$$\alpha A=\frac{1}{3600}\sqrt{\frac{\gamma}{2g}}\cdot a\cdot \Delta p^{1/n-1/2} \qquad \cdots\cdots\cdots\cdots\cdots (1)$$

Where αA : equivalent leakage area (m^2)

γ : density of air (kg/m^3)

g : gravity acceleration ($9.8 m/s^2$)

Δp : pressure drop across the building envelop (Pa)

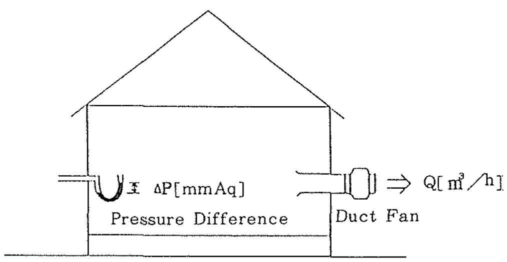


Fig. 1 Major Components of Apparatus

n : an exponent ($1 \leqq n \leqq 2$)

a : flow rate at $\Delta p = 9.8$ Pa

Figure 2 shows the results of this measurement in the relation between the total floor area and the equivalent leakage area. The degrees of airtightness of measured houses extend over a wide range. The degree of airtightness of the traditional wooden frame house is very low, and this tendency is the same even in the new by built houses.

The symbol ⊕□△ shows the results of new houses built by the improved construction methods. The mean value of equivalent leakage area per unit floor area is about $3.5 cm^2/m^2$. Although this value is less than that of the ordinary traditional frame construction method of $9.0 cm^2/m^2$ (symbol○) is much larger than the value of Swedish standards of $1.8 cm^2/m^2$. This means there is a need of much improvement or basic change in the traditional frame construction method. The airtightness of the highest degree in Hokkaido now is exceeding the Swedish standards.

On the other hand, as most people think that the purpose of airtightening is only to decrease all cracks in the whole house and is not expected to change their heating custom or

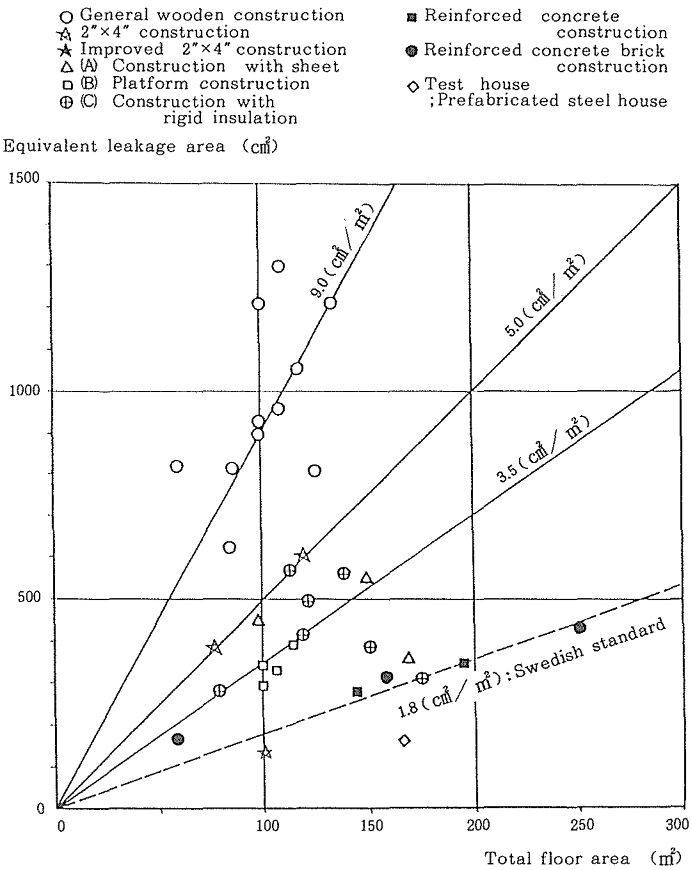


Fig. 2 Results of Measurement of Equivatent leakage Area

to insert openings at the exterior for moisture exclusion, and this leads to new problems such as vapour condensation or mold formation especially in the cold rooms or in the insulated walls which can become a very serious problems. Needless to say, the purpose of airtightning is not to decrease useful ventilation but to provide a solution to these problems.

3. Natural Ventilation by Wind Fluctuation

Natural ventilation in the traditional Japanese house is greatly influenced by wind velocity and its direction. And to some extent people welcome wind especially in summer. (There are many picturesque names for wind in Japan as 2145.)

Though the main purpose of airtightning in the house is to make it possible to use a heat recovering system and to increase the ventilation rate without increasing heat loss, moreover in this respect how to use the wind power for ventilation is also a very interesting and traditional concern for us especially when the moisture removing ventilation is important.

For these purposes it is important to know the characteristics of the natural ventilation by wind more clearly. There are many methods for the calculation of ventilation rates. However no calculation methods are adaptable. This is because the calculation of ventilation by wind mainly use the mean value of fluctuating wind pressure.

Fundamentally, the wind pressure on the wall of building is fluctuates with wind itself and furthermore air is like a constrictive fluid. Under the fluctuating conditions of air pressure, this constrictive nature should not be neglected. Besides the air flow resitance of cracks, the elasticity of air mass behind it, frequency of fluctuation, depth of the crack and etc. should be taken into consideration in the mass balance equation.

The authors have forth led a new calculation method for wind ventilation based on the character of constrictability of air above mentioned.
Assuming the following items,

a) Air in the crack moves as a mass
b) Space behind the crack works as a spring
c) Flow resistance of the crack can be obtained by the measurement under a steady state condition

From these assumptions, we made several dynamic models for the analysis. When the space has only one crack on the oneside of a wall as in fig.3, the motional equation of the mass of air in the crack can be expressed as follows ;

$$m\ddot{x}+c\dot{x}+kx=p \qquad \cdots\cdots\cdots\cdots\cdots \quad (2)$$

where, m : mass of air (kg)
c : resistance of crack (kg/s)
k : elastic constant of air in the space (kg/s^2)
x : moving distance of air in the crack (m)

p : fluctuating wind pressure (Pa)

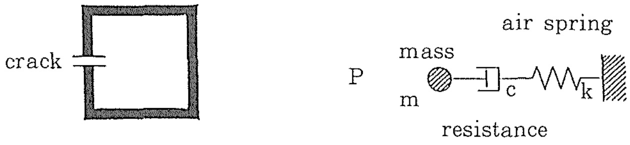


Fig. 3 Modelization of space with single opening

In the same manner, when the space has two cracks on the opposite side of the wall as fig.4, the motional equations of the masses can be expressed as follows ;

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix}+\begin{bmatrix} c_1 & 0 \\ 0 & c_2 \end{bmatrix}\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix}+\begin{bmatrix} k & -k \\ -k & k \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}=\begin{bmatrix} P_1 \\ P_0 \end{bmatrix} \cdots\cdots (3)$$

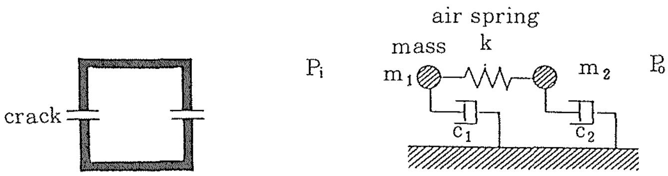


Fig. 4 Modelization of space with two openings

And the ventilation rate can be obtained by adding effective quantity that is corrected with the depth of crack as shown in fig.5.

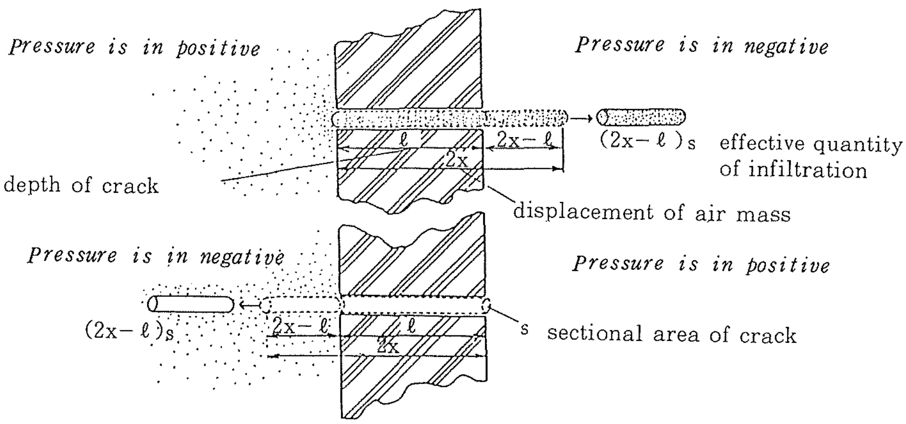


Fig. 5 Displacement of air in the crack

To verify these assumptions, the authors have measured actual ventilation rate using tracer gas of co_2 in the test chamber as in fig.6. The variations of air pressure in this test chamber were made with a large cone type speaker. It was possible to simulate free waves of pressure fluctuation on the crack such an in actual wind pressure on the wall in the test chamber.

When the pressure difference between two spaces varies as sine-wave, the equation becomes as follows ;

$$m\ddot{x}+s^{n+1}/a^{n}\dot{x}^{n}=s\ p\sin(\omega t) \qquad \cdots\cdots\cdots\cdots\cdots (4)$$

The ventilation rate through the crack is obtained by solving the balance equation of concentration of tracer gas. Figure 7 shows the results of calculation and experiments. Both results are almost the same, though there can be a little difference in high frequencies over 1 Hz. This difference between calculation and experiment will be neglected, because there is little energy in the high frequency of wind fluctuation.

In comparing the results of the ordinary method with this new method, the characteristics of both methods will be clear. Figure 8 shows each result. The calculation was done by a measured wind fluctuation data at the flat house on 13-th floor of a 14-storied building. And the measurement of ventilation rate of this house was done by utilizing CO_2 as the tracergas at the same time. The results show that the ordinary method can produce a greater error than new method. And it is found that the dynamic analysis method as we explained is necessary to know the ventilation rate in the case where wind pressure fluctuates.

Figure 9 shows a model of a cavity in a double wall or double sashed window having small cracks on both sides. If the fluctuating wind pressure on the outside is lower than

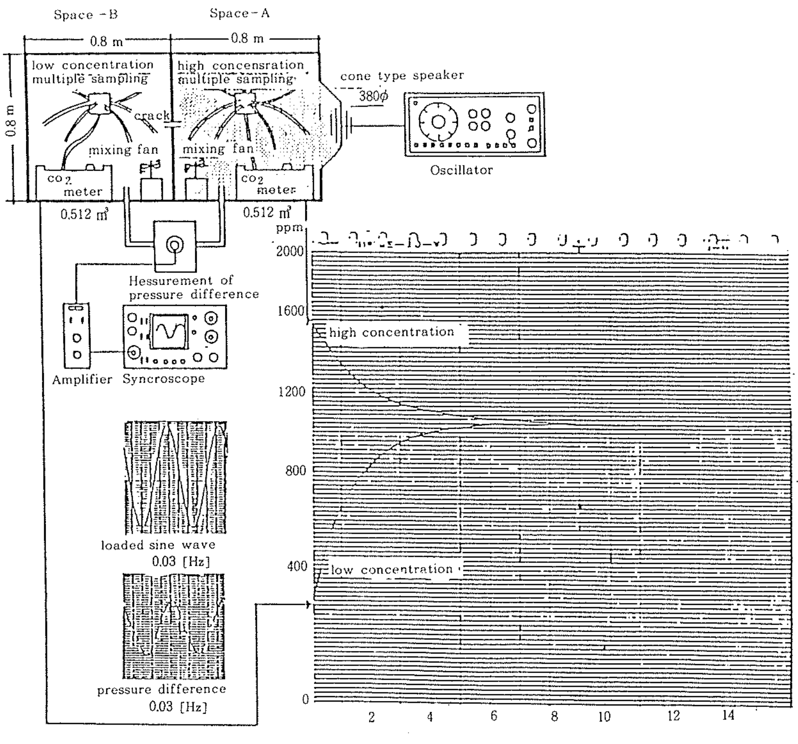


Fig. 6 Test enclosures and test method

the inside pressure and the constrictivity of air in a cavity is not considered, ventilation from the outside can not be expected. But practically when the inside crack is smaller than the outside cracks, reciprocating shuttle ventilation occurs through the outside crack even when the wall is to the leeward.

Figure 10 shows the result of calculations by equation (3). Percentage of the outside air means the ventilation from the outside. The figure shows that even when the outside pressure is negative the ventilation from the outside can be expected as long as the inside crack is small enough (c_2/c_1 becomes small) and the standard deviation of wind pressure becomes higher.

This effect of wind fluctuation is very useful for a dehumidifying ventilation in an airtightened house.

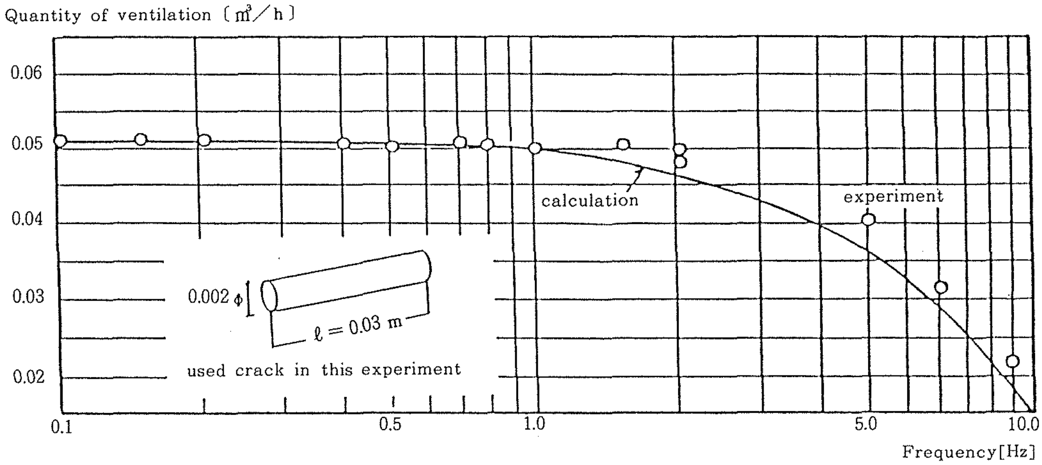


Fig. 7 Results of calculation and experimental value

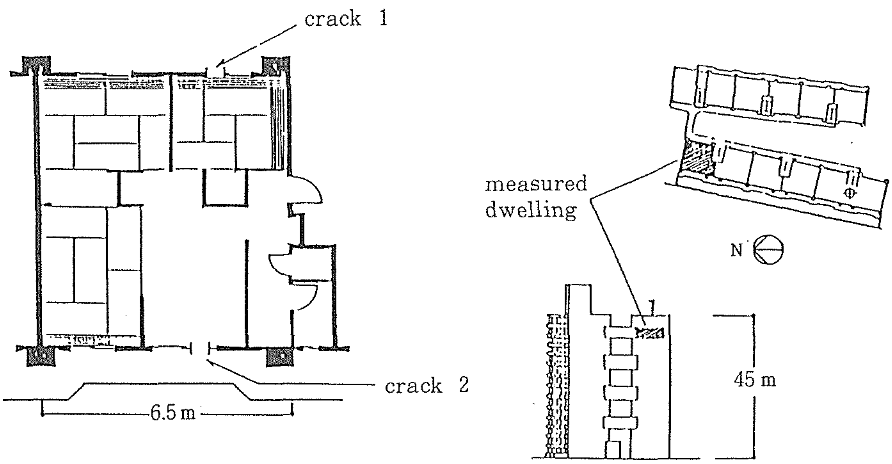
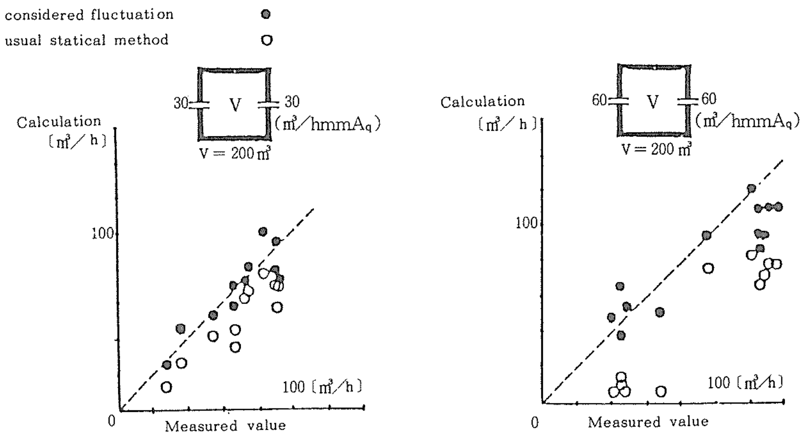


Fig. 8(a) Measured dwelling and its location



(a) Flow rates of cracks are 30 m³/hmmAq on each site

(b) Flow rates of cracks are 60 m³/hmmAq on each site

Fig. 8(b) Comparison the results of calculation with the measured value

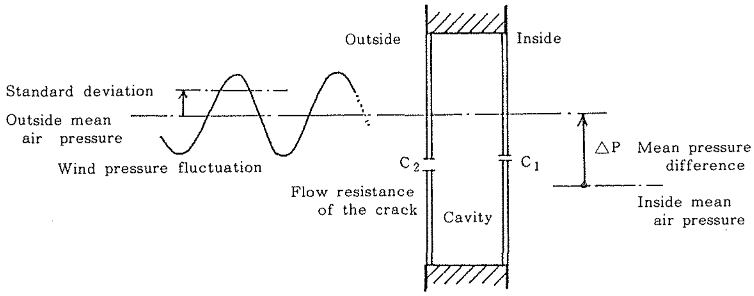


Fig. 9 Model of a cavity and cracks

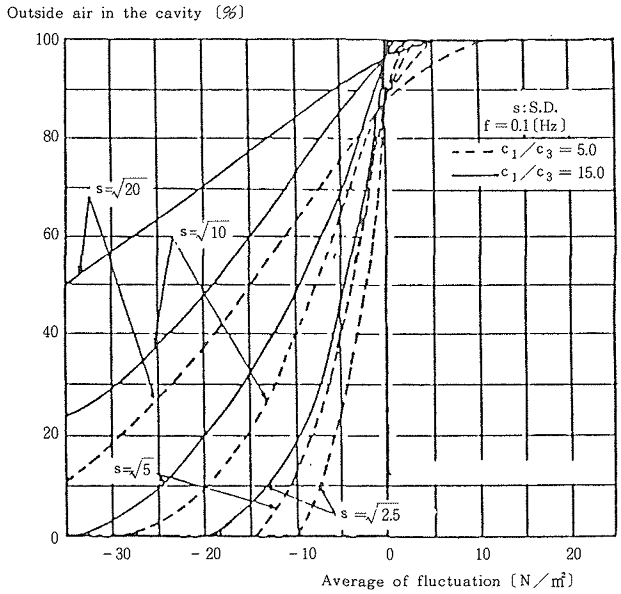


Fig. 10 Outside air in the cavity and standard deviation of fluctuation

4. Design of Ventilation Routes

From the stand point of health ventilation in a house, natural ventilation is not desirable to be fluctuate greatly by the wind velocity or its direction. According to the analysis mentioned above, it is one solution to make both inlet and outlet of ventilation on the same side of the wall. Designing of ventilation route is also important in an airtightened house. Figure 11 shows the image of ventilation routes in a house. The waste interior air of a house should be exhausted from the toilet, bathroom, kitchen and other spaces which generate odor, gas or vapor. Fresh outdoor air through limited inlets should be diffused to living room, bed rooms, and nurserys. However if it is done by this way of ventilation with no processing to the inlet and outlet air, the heat loss by ventilation will increase rapidly.

A heatexchanger or a heatrecovering ventilation system is needed as in fig.12.

Using the high efficiency heatrecovering system, it will allow the fresh outdoor air to come in without much heat loss. And this is one of the purposes of airtightening.

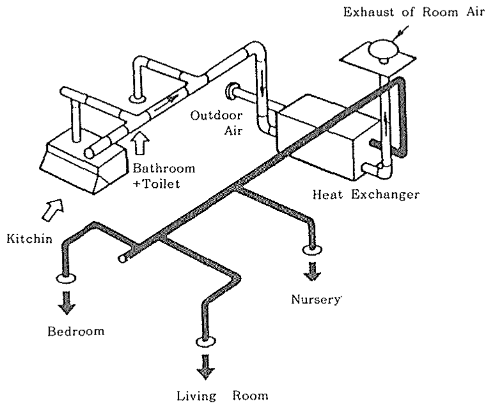


Fig. 11 Ideal Ventilation Routes

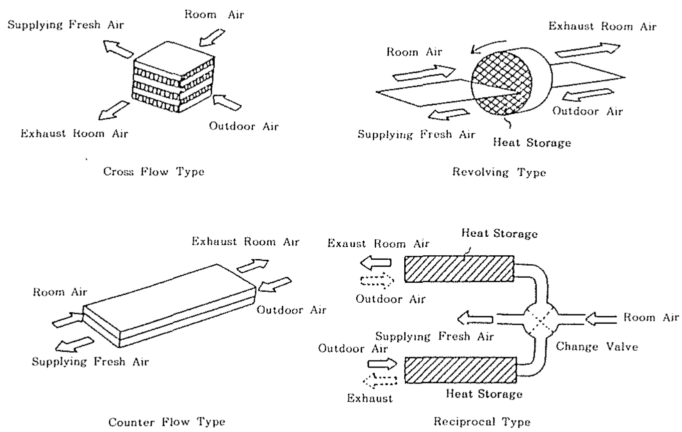


Fig. 12 Heat Recovering System

5. Measurement of Ventilation Routes with Multi-tracergases

To check the designed ventilation routes, the authors have developed a method for measurement of ventilation rate in the spaces using multi-tracergases. We verified this method in a test chamber with three rooms as shown in fig.13.

In this test chamber, if the different tracergases are generated at the same time and the concentrations are measured, the balance equation of each tracergas is obtained in each chamber as follows ;

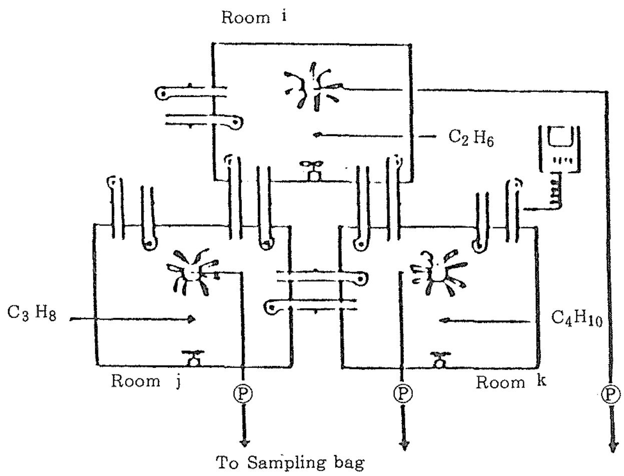


Fig. 13 Test Chamhers

$$\left.\begin{array}{l}
\begin{bmatrix} (C_j^i-C_i^i) & (C_k^i-C_j^i)-C_i^i \\ (C_j^j-C_i^i) & (C_k^j-C_j^j)-C_i^k \\ (C_j^k-C_i^k) & (C_k^k-C_i^k)-C_i^k \end{bmatrix} \begin{bmatrix} Q_{ji} \\ Q_{ki} \\ Q_{oi} \end{bmatrix} = \begin{bmatrix} -M_i \\ 0 \\ 0 \end{bmatrix} \\
\begin{bmatrix} (C_i^i-C_j^i) & (C_k^i-C_j^i)-C_j^i \\ (C_i^j-C_j^j) & (C_k^i-C_j^j)-C_j^j \\ (C_i^k-C_j^k) & (C_k^k-C_j^k)-C_j^k \end{bmatrix} \begin{bmatrix} Q_{ij} \\ Q_{kj} \\ Q_{oj} \end{bmatrix} = \begin{bmatrix} 0 \\ -M_j \\ 0 \end{bmatrix} \\
\begin{bmatrix} (C_i^i-C_k^i) & (C_j^i-C_k^i)-C_k^j \\ (C_i^j-C_k^j) & (C_j^j-C_k^j)-C_k^j \\ (C_i^k-C_k^k) & (C_j^k-C_k^k)-C_k^k \end{bmatrix} \begin{bmatrix} Q_{ik} \\ Q_{ik} \\ Q_{ok} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -M_k \end{bmatrix}
\end{array}\right\} \cdots\cdots\cdots\cdots\cdots \quad (5)$$

If the generation of tracergases is constant, each ventilation rate will be obtained from the simultaneous equations. When the generation is pulsive, the concentration of steady state condition is equal to the integrated value of the response of concentration. That is,

$$C_i^i(t)=\int_0^t \psi_i(\tau)\ M_i(t-\tau)d\tau \qquad C_i^i=1/\Delta t\int_0^\infty C_i^i(t)dt$$

$$C_j^i(t)=\int_0^t \psi_j(\tau)\ C_i^i(t-\tau)d\tau \qquad C_j^i=1/\Delta t\int_0^\infty C_j^i(t)dt$$

$$C_k^i(t)=\int_0^t \psi_k(\tau)\ C_i^i(t-\tau)d\tau \qquad C_k^i=1/\Delta t\int_0^\infty C_k^i(t)dt$$

In the same manner,

$$C_i^j=1/\Delta t\int_0^\infty C_i^j(t)dt \qquad C_i^k=1/\Delta t\int_0^\infty C_i^k(t)dt \qquad M_i=\Delta M_i/\Delta t$$

$$C_j^j=1/\Delta t\int_0^\infty C_j^j(t)dt \qquad C_j^k=1/\Delta t\int_0^\infty C_j^k(t)dt \qquad M_j=\Delta M_j/\Delta t$$

$$C_k^j=1/\Delta t\int_0^\infty C_k^j(t)dt \qquad C_k^k=1/\Delta t\int_0^\infty C_k^k(t)dt \qquad M_k=\Delta M_k/\Delta t$$

where, C_i^j : response of concentration at room-i (ppm) due to the tracergas generation in the same room-i (or in another rooms)

Q_{ij} : vetntilation rate from room i to room j (ml/h)

ψ_i : unit pulsive response in room i (ppm/h)

M_i : steady generation rate of tracergas in room i (ml/h)

The ventilation rate in each route is obtained by using equations if the generation time dt is known.

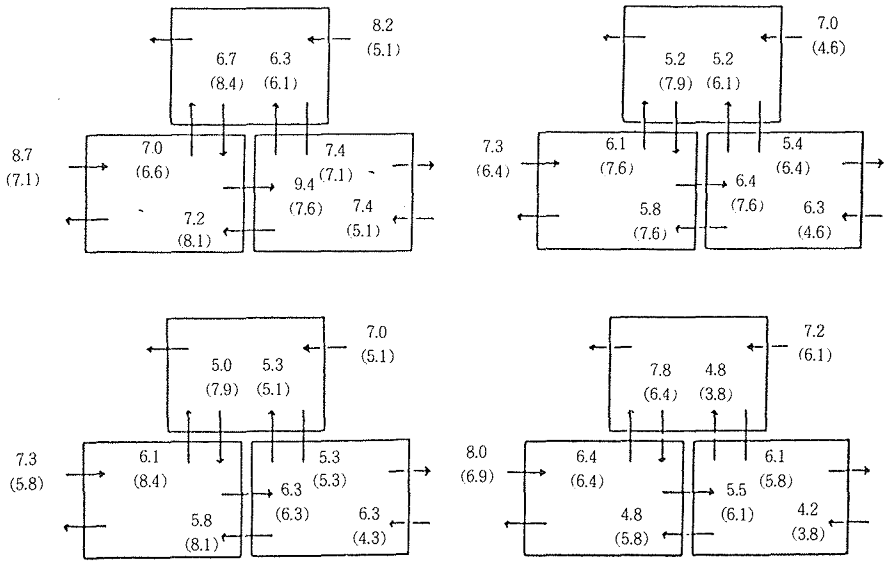


Fig. 14 Results of Measurements

In this measurement, different kinds of tracergas were generated at the same time in each room and sample gas was inhaled constantly in each room and obtaining the concentrations of three kinds in each room by using the flame ionization detecter.

In this way integrated concentration value or mean concentrations of each gas are obtaining by one sampling in each room. As for the standard flow rates, calibrated values were obtained by the measurement of air velocities in connecting ducts. The results are shown in fig.14.

The values from the tracergas method are almost the same as the standard air flow. But there remain some issues to be examined for the measurement of concentration such as purity of gas or unevenness of mixing.

6. Conclusions

As the airtightening can not be considered in the traditional Japanese houses, there are many difficulties to make the house airtightened even in cold region of Hokkaido. Airtightening of the house should be done to make it possible to heat a whole house without unheated space and to ascertain whether the exhaust moisture is expelled outside.

The studies in this report were done to induce changes in thinking of the custom and thought. Although the airtightness of the house is improving now a days, increasing airtightness is necessary for the change of the custom without increasing fuel consumption. And the direction or the routes of ventilation in a house or a wall should be considered.

In a wooden construction having cavities for insulation, wind power especially its fluctuating pressure is very important for the ventilation of moisture removing. Fundamental studies on ventilation under the fluctuating wind pressure give us not only new calculation methods but also some ideas for the use of wind power, and also a way to eliminate the wind effect on stable ventilation.

A measuring method of ventilation between multi spaces is useful to know the actual condition of ventilation with its routes.

7. Acknowledgement

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