DESIGN OF VENTILATION ROUTES AND INDOOR AIR QUALITY IN HOUSES USING A PASSIVE VENTILATION SYSTEM

M. Hayashi[1], M. Enai[2], Y. Hirokawa[3] and M. Yamashita[3]

1 Miyagigakuin women's college, Japan
2 Graduate School of Engineer of Hokkaido University, Japan
3 School of Design and Architecture of Nagoya City University, Japan

ABSTRACT

The feasibility of designing ventilation routes in the house with passive ventilation system is investigated using the numerical experiments and the measurements on its ventilation rates and indoor air quality. As a result, the ventilation design using the used-air in the rooms on the second floor is proved to be one of the simplest ways to keep good indoor air quality. And the required airtight level of the house with the ventilation design is lower than that with the general ventilation design where the air is supplied to every room.

INTRODUCTION

Designing the ventilation routes is very important to keep indoor air quality in houses with passive ventilation. The authors have shown a method of designing ventilation routes using a preheat room and an air supply chamber in detached houses with passive ventilation. But the method is not suitable for general houses, because of the high cost and the high required airtight level. To seek for the feasibility of introducing the passive ventilation in general houses, a ventilation design using "used-air" is investigated in this report.

METHODS

1. Numerical experiments on the ventilation routes and the required airtight levels

The airtight level has a large influence on the ventilation routes in houses with passive ventilation. Fig.1 shows air supply methods in houses with passive ventilation. The ventilation routes must be designed as follows to keep good indoor air quality with a low ventilation rate. The fresh air is led to the rooms and the air is exhausted from the dirty zone that consists of toilets, kitchens and bathrooms. This ventilation route is called type-A in the report. But in the houses with the direct air supply method shown in Fig.1-1, if the airtight level is not enough, the air flows back through the openings in the rooms on the second floor. The method of supplying preheat air from the bottom does not have such a problem, but it is necessary to design air supply routes to the rooms on the second floor. The ventilation designs shown in Fig.1-2 and Fig.1-2', in which the stairwells are used as the ventilation routes to supply air to the rooms on the second floor, are useful methods. In the report, the air supplied through other rooms is called "used-air" and the ventilation route is called type-B.

The calculation method of the airflow ratios considering the airtight level is as follows. First, the required airflow rate through the stack : Q_{rqst} is decided to meet the ventilation requirement : Q_{rq}. The airflow ratios of the openings are calculated to meet the required ventilation rates in rooms considering the filtration. In houses using the direct air supply method, the ratio on the second floor must be larger than that on the first floor by the stack effect. And when the size of the opening on the second floor reaches the maximum, Q_{rqst} must be set higher. The airflow ratios of the stack and the openings in a model of general house were calculated on the following conditions.

(1) The equivalent leakage area per its surface area of the envelope is constant.

(2) The pressure difference between inside and outside: $\Delta P(h)$ is described as follows.

$$\Delta P(h) = (H_{nt} - h)\cdot(\gamma_{in} - \gamma_{out}) \quad \cdots\cdots\cdots(1)$$

H_{nt}:[$\Delta P(H_{nt}) = 0$] (m), γ_{out} (γ_{in}): weight ratio of outside air (that of indoor air) (kg/m^3)

(3) The wind pressure is out of consideration.

(4) The fresh air supply rate is the sum of the air supply rates through the designed openings and the infiltration rate.

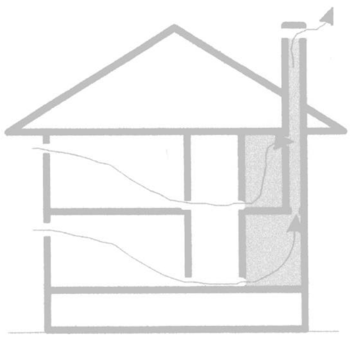
The ventilation performances were estimated using the ratio of the designed ventilation rate : R_{vent} and the ratio of the designed air supply rate : R_{supply}. These ratios are calculated as follows.

$$R_{vent} = Q_{rq} / Q_{all} \cdot 100 \quad \cdots\cdots\cdots (2) \qquad R_{supply} = Q_{sup} / Q_{all} \cdot 100 \quad \cdots\cdots\cdots (3)$$

Q_{all} : ventilation rate (m^3/h), Q_{sup}: air supply rate through the designed openings.

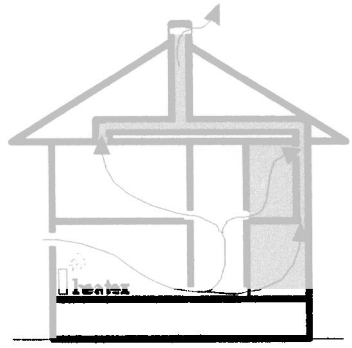
2. Numerical experiments on the ventilation routes and the indoor air quality

The calculation program named "Fresh" is composed of the following methods. The temperature, heating and cooling load are calculated using Duhamel's integration method. And the airflow rates in the multi-cell system are calculated using the equations of the powers at the openings considering the stack effect, the wind pressure and the mechanical power. The equations are solved using Newmark's method. They are calculated using the standard weather data :HASP from Society of Heating, Air-conditioning and Sanitary Engineers of Japan. The concentrations of pollutants are calculated using the equations of the amount of



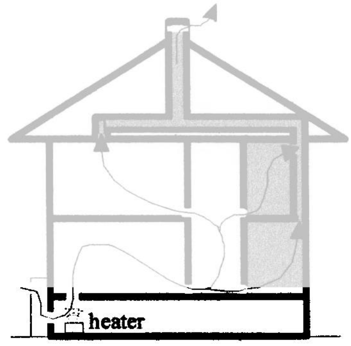
type-A / direct air supply

Fig.1-1



type-B / air supply from the bottom

Fig.1-2



type-B/ air supply from the bottom

Fig.1-2'

Figure 1. Air supply methods and ventilation routes of the passive ventilation

pollutants. The emission rates of pollutants are calculated using the results of the survey on the Japanese daily schedule by NHK. The daily schedule of each member of the family in a house is simulated considering the plan of the house. The ventilation rates and the concentrations of CO_2 and formaldehyde are calculated in model houses with two types of ventilation route.

3.The measurements of ventilation rates and indoor air quality in the detached houses

The ventilation rates and the indoor air quality were measured in two experimental houses shown in Fig.2 and Table1. The passive ventilation systems in the houses are shown in Fig.1-2. The used-air is reused in the rooms on the second floor. The ventilation rates were measured using the constant concentration method. The concentration of tracer gas: SF_6 was controlled to be 10 PPM using the system shown in Fig.3. The indoor air quality was measured using the tracer gas: CO_2. The tracer gas was injected according to a simplified daily schedule model. The method is called "pattern injection method" in this report.

RESULTS

1. Numerical experiments on the ventilation routes and the required airtight levels

The relationship between the required airflow rates through the stack: Q_{rqst} and the airtight levels : C is shown in Fig.4. Q_{rqst} increases with C. And Q_{rqst} in houses with type-A is larger than that with type-B. The ratio of designed ventilation rate : R_{vent} and the ratio of the designed air supply rate : R_{supply} are shown in Fig.5. The ratios decrease with C. The ratios in houses with type-A are smaller than those with type-B. The ratios decrease with the temperature difference: $\Delta\ \theta$. When R_{vent} of type-A is needed to be larger than 80%, the required airtight level is

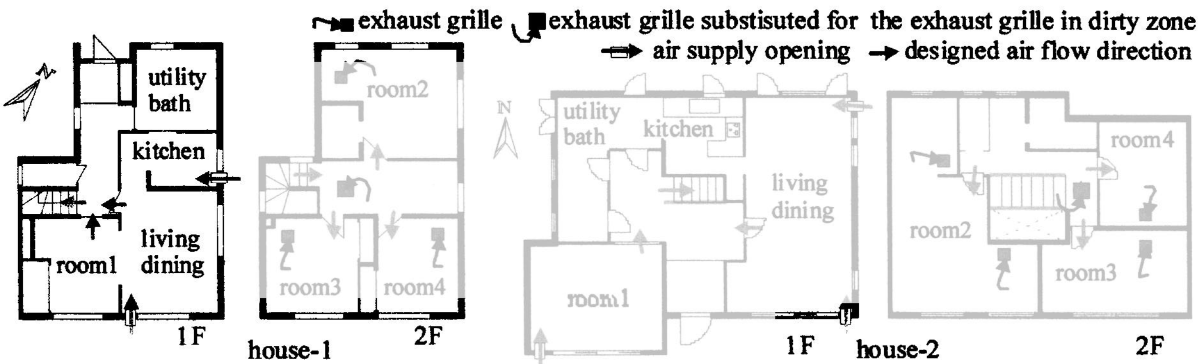


Figure 2. The experimental houses with passive ventilation system

Table 1. Performances of the experimental houses

Number	1	2
floor area (m^2)	128	168
equivalent leakage area (cm^2/m^2)	0.5	4.0
specific heat loss coefficient (W/Km^2)	1.6	4.2
airflow ratio of stack ($m^3/hmmAq^{1/1.5}$)	200	
place in Japan	43 deg N.lat	35 deg N.lat

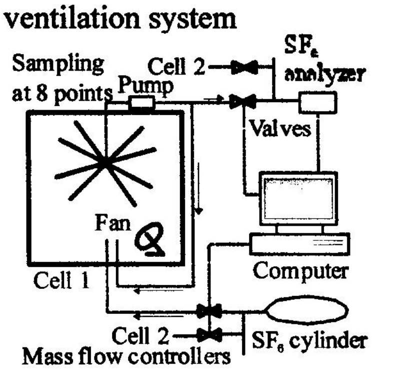


Figure 3. The measuring system

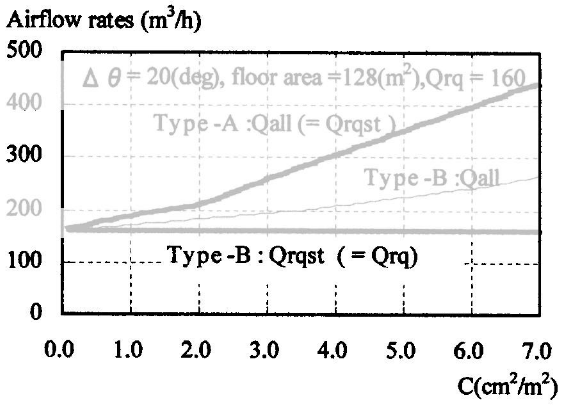


Figure 4. The calculated airflow rates

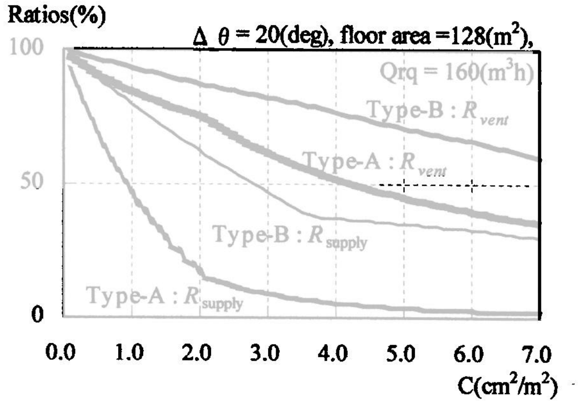


Figure 5. The calculated ratios

very high. The limit of C is 1.5, which is larger than the latest Japanese standard in the cold region of Japan : C = 2.0. In the case of type-B, the required airtight level is lower. The limit of C is 3.4 and R_{supply} is very high : 85%. So, it is very easy to design the ventilation routes with type-B.

2. Numerical experiments on the ventilation routes and the indoor air quality

Two types of ventilation routes shown in Fig.1-1 and Fig.1-2 are designed in the general house of which the floor area is 124 m^2 for a couple and the two children. In the house with type-A, the air supply rates to rooms are designed to meet 20(m^3/h person) and the designed air supply rate to LDK is 70(m^3/h). And the air exhausted form the dirty zone at the rate of 150(m^3/h). In the case of type-B, the designed air supply rate to LDK is 150(m^3/h). And the used air is led to the rooms on the second floor from LDK. The air is exhausted form the

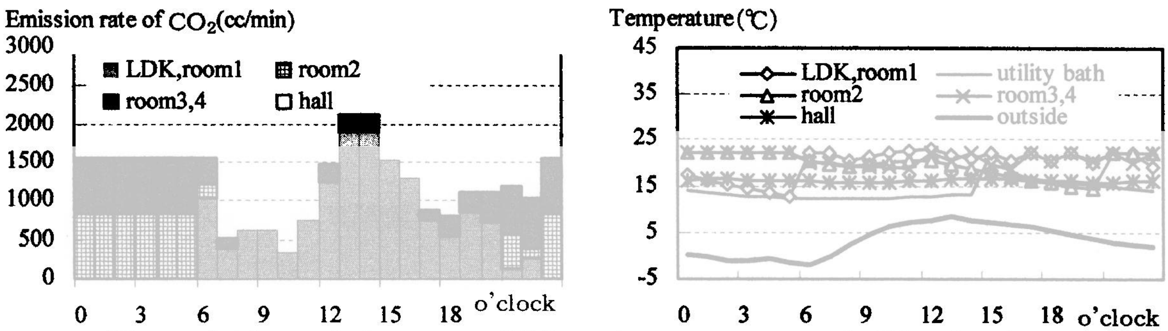


Figure 6. The emission rates of CO_2 and temperatures on holiday in winter

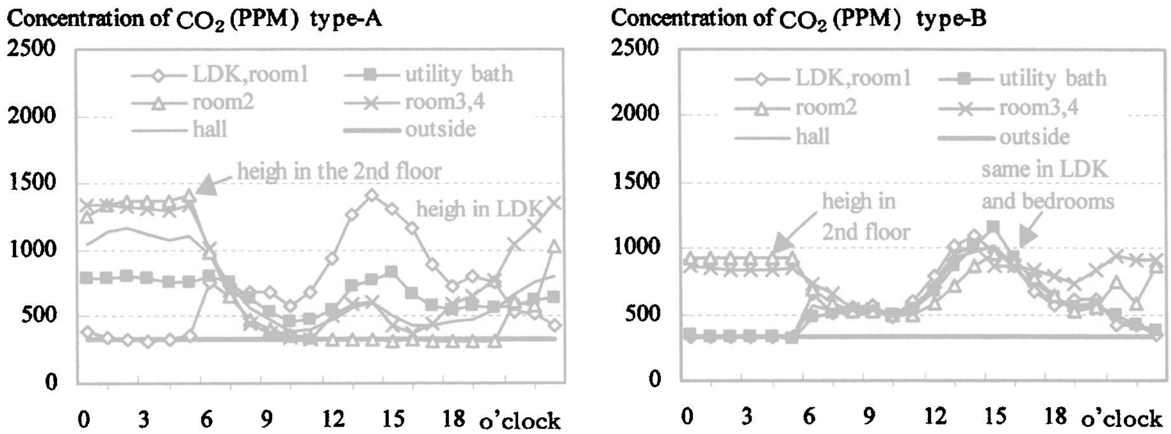


Figure 7. The concentrations of CO_2 on holiday in winter

rooms on the second floor at the rate of 150 (m^3/h). These airflow rates are designed on the condition that the temperature difference is 20 (deg). The ventilation rates and the concentrations of the pollutants in these houses are calculated for a week in February. Fig.6 shows the emission rates of CO_2 on holidays, the calculated temperatures and concentrations. The concentrations in the house with type-A change with the emission rates in the rooms. In the case of type-B, the concentrations in the rooms on the second floor are influenced by the concentrations on the first floor as shown in Fig.7. And Fig.8 shows the concentrations of formaldehyde if the emission rate per its floor area is 0.1 (cc/hm^2). The concentrations in the rooms on the second floor are higher than that on the first floor in type-A and type-B and the concentration in LDK on the first floor is the lowest in the case of type-B. The weekly averages of the concentrations when people use the rooms are shown in Fig.9. The average of the CO_2 concentrations in the case of type-A is larger than that in the case of type-B. The average of the formaldehyde concentrations in the case of type-A is almost the same as that in the case of type-B.

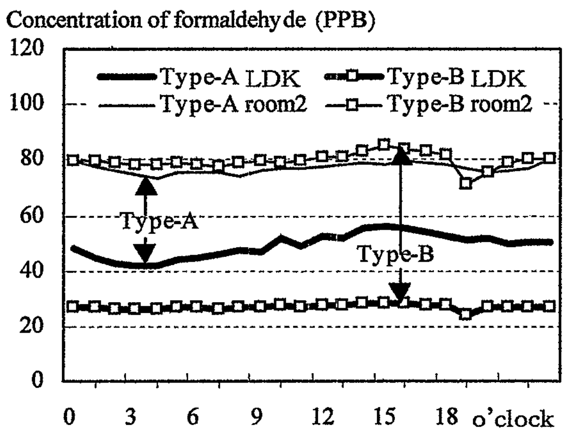


Figure 8. The concentrations of formaldehyde on a holiday in winter

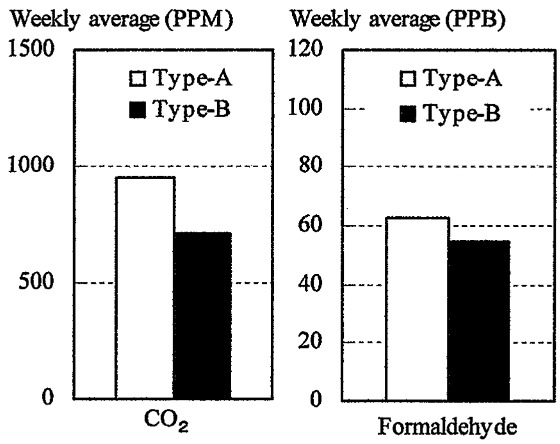


Figure 9. The average of concentrations when people use the rooms

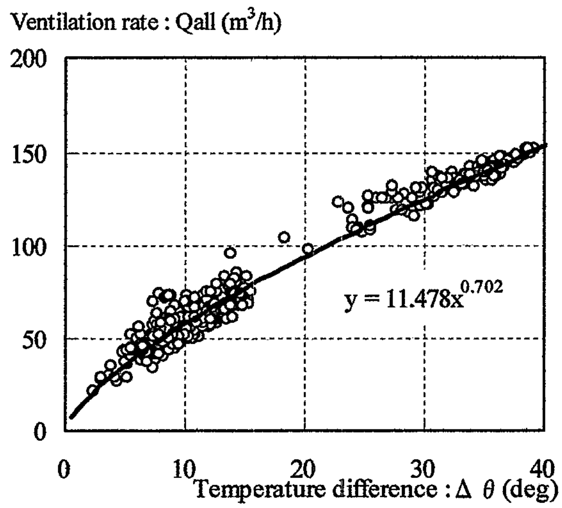


Figure 10. The ventilation rates and the temperatures difference in house-1

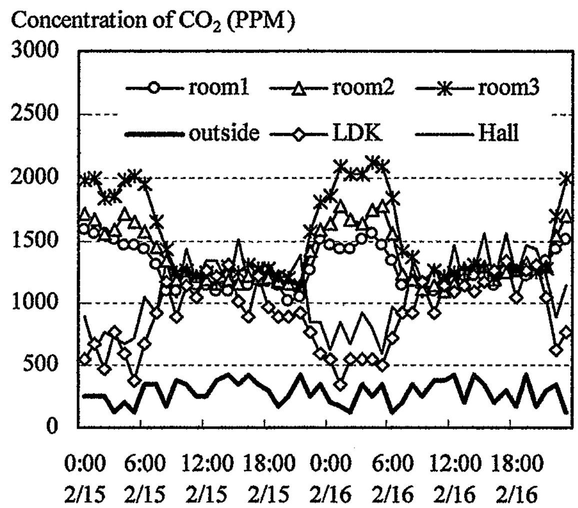


Figure 11. The concentrations of tracer gas in house-1

3. The measured ventilation rates and indoor air quality in the experimental houses

The ventilation rate increases with the temperature difference as shown in Fig.10. Fig.11 shows the concentrations of tracer gas when the gas is injected in LDK in the daytime and in the rooms on the second floor in the nighttime. The injection rate of the tracer gas is 2000 (cc/min). The rate is 1.5 times of the general emission rate in the case of a family of four. The daily change of the concentration of the tracer gas is almost the same as that of the calculated concentration of type-B using the general daily schedule of Japanese families. The relationship between the ventilation rates and the daily averages of the concentrations is shown in Fig.12. The averages and the peaks decrease with the ventilation rates. And the averages of the concentration when people use the room is almost the same as the ratio of the injection rate divided by the daily averages of the ventilation rate.

DISCUSSION

The results of the investigation show the followings. The ventilation characteristics are influenced by the airtight level, the ventilation routes and the air supply methods. The ventilation rates and the routes of type-B are stable at almost all the airtight levels of the latest general Japanese houses in contrast with type-A. And the ventilation design with type-B keeps the indoor air quality acceptable by the effect of the used-air. When the ventilation system with type-B is designed, the crawl space under the first floor is suitable for preheating and distributing the supplied air. The authors expect that the ventilation design using the used-air with type-B will be one of the standard ways to realize the passive ventilation systems in general houses.

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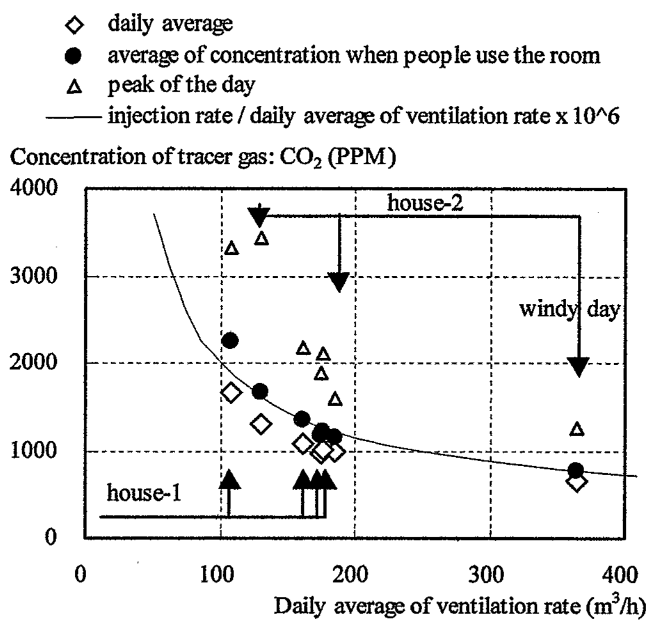

Figure 12. The ventilation rates and the concentrations of tracer gas