PERFORMANCE OF PASSIVE STACK VENTILATION WITH HEAT RECOVERY SYSTEM

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ABSTRACT

In order to explain the effect of heat recovery on a passive ventilation system using stack effect, and to show the factors and conditions that the heat-recovery system can be installed in a passive ventilation system, the following investigations are made. The characteristics of the airflow in houses using the passive ventilation with the heat recovery units were investigated from scale model experiments and numerical experiments. And the effect of energy saving by the heat recovery system was investigated from numerical experiments using the standard weather data of cities in Japan. The results show that the factors in realizing the systems are the airtight level of houses and the airflow ratio of the stack with the heat recovery unit.

INTRODUCTION

With the elevation of demand level for thermal comfort and energy saving, the airtight level of Japanese general houses has been higher but IAQ problem has emerged. A ventilation design utilizing natural force is one way to solve the problem. And it is possible to realize such a ventilation design in airtight houses. The ventilation rates in houses with passive

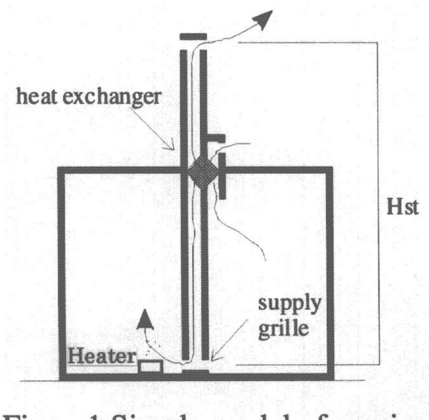

Figure1 Simple model of passive ventilation with heat exchanger

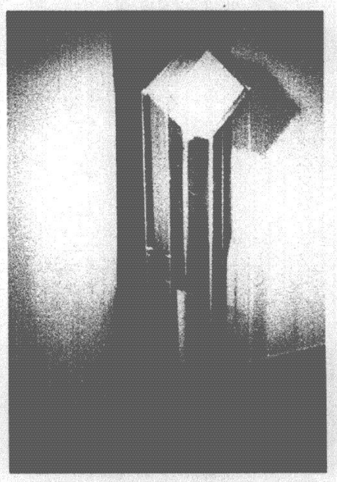

Figure 2 Simplified model

Figure 3 Airflow traced by smoke

ventilation systems change with the temperature difference and wind pressure. So the control of the ventilation rate and the heat recovery are necessary to decrease the energy loss with ventilation. The main force of the passive ventilation is caused by the difference between the temperature of indoor air and that of outside air. So the heat exchange between the exhaust air and the supply air decrease the force. To realize the passive ventilation system in detached houses, the required performance of heat exchanger and stack must be made clear considering air leakage. The report shows the results of investigation on a passive ventilation system with a cross counter-flow heat exchanger.

METHODS

1) Experiment of airflow direction in the ventilation system using smoke tester

Figure 2 shows the simplified model of the ventilation system. The airflow is made using a heater and is traced using a smoke tester as shown in Figure 3.

2) A basic equation of ventilation rate considering the heat exchange ratio

A simple model of passive ventilation with a heat exchanger is shown in Fig.1. The airflow rate through the stack is explained with the following equation. The equation means the balance of airflow rates in a house.

$$V_{sp} = A_{sp} \cdot \{ \omega \cdot H_{st} \cdot (1-\psi) \cdot \Delta\theta \}^{1/n} \cdots\cdots (1)$$

V_{sp}: supply airflow rate (m^3/h) [$=V_{ex}$], V_{ex}: exhaust airflow rate through the stack (m^3/h) A_{sp}: airflow ratio of the supply route ($m^3/hmmAq^{1/n}$), H_{st}: height of stack from the supply grille (m), ψ: heat exchange ratio (-), n: ratio of airflow ($1<n<2$), $\Delta\theta$: difference of temperature between inside air and outside air (K), ω: ratio of pressure difference to temperature difference (= 0.0043)

3) Numerical experiments of energy loss considering the filtration

In a house with a leakage, the exhaust airflow rate through the stack is larger than the supply airflow rate through the supply grille because of the infiltration through the leakage. In order to explain the energy loss with ventilation in houses with a heat exchanger and a leakage, the following equations on the temperature in the heat exchanger are necessary.

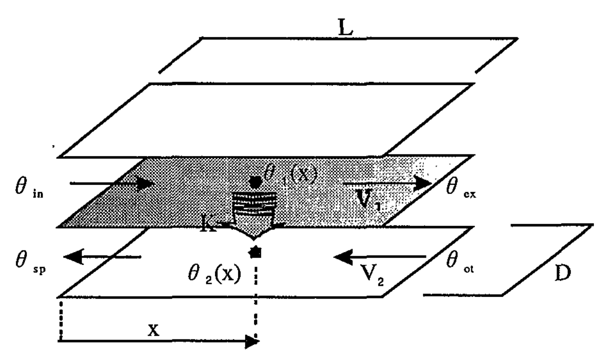

Figure 4 Model of heat exchanger

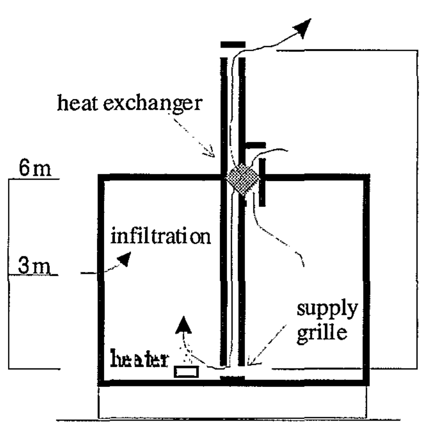

Figure 5 Model of house with leakage

$$\theta_1(x) = \alpha_1 e^{-\beta x} + \gamma \quad \cdots\cdots\cdots\cdots (2)$$

$$\theta_2(x) = \alpha_2 e^{-\beta x} + \gamma \quad \cdots\cdots\cdots\cdots (3)$$

$\alpha_1 = A_1(\theta_{in} - \theta_{ot}) / (A_1 - A_2 e^{-(A1-A2)L})$, $\alpha_2 = A_2(\theta_{in} - \theta_{ot}) / (A_1 - A_2 e^{-(A1-A2)L})$, $\gamma = \theta in - \alpha_1$, $A_1 = KD/(CV_1)$, $A_2 = KD/(CV_2)$, C: thermal ratio of air (w/m^3K), K: thermal transmittance (w/m^2K)

The airflow rates in the simplified 2-story house model of which floor area is 124(m^2) are calculated using the equation considering the infiltration.

RESULTS

1) Basic characteristics of the passive ventilation system with a heat exchanger

The ventilation rates increase with the temperature difference and the height of stack as shown in Fig.6. Fig.8 shows the relationship between the airflow ratio and the heat exchange ratio on condition that the ventilation rate meets the ventilation requirement. Fig.9 shows the relationship between the energy loss and the airflow ratio on the same condition. These results

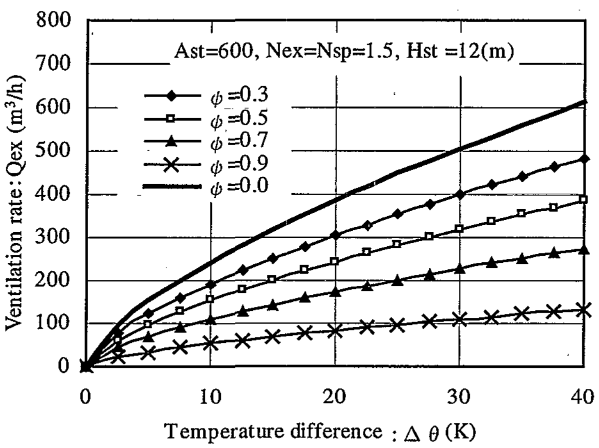

Figure 6 Temperature difference and ventilation rate

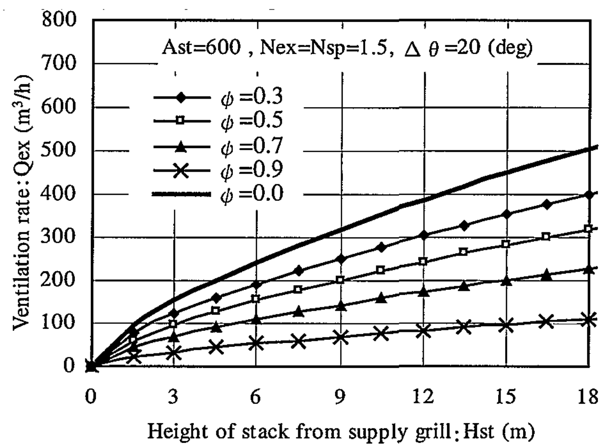

Figure 7 Height of stack and ventilation rate

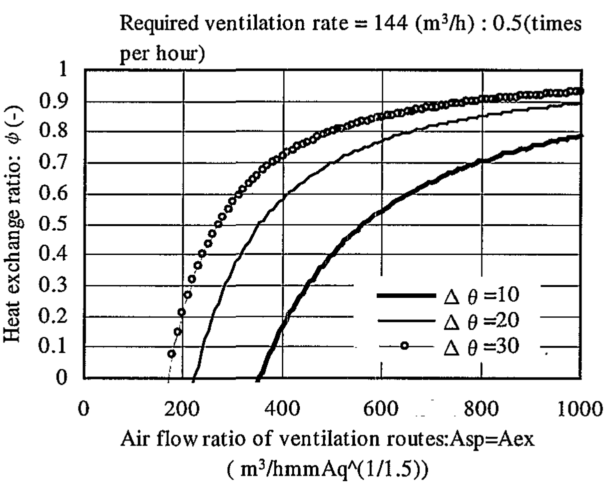

Figure 8 Heat exchange ratio when ventilation rate meets the ventilation requirement

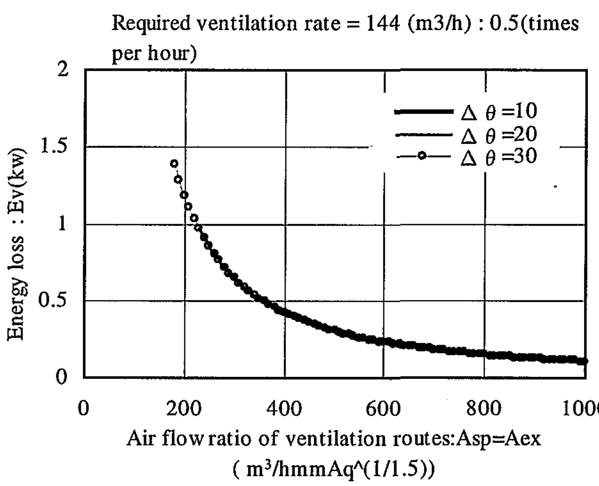

Figure 9 Energy loss when ventilation rate meets the ventilation requirement (C=0)

show that the high airflow ratio and high heat exchange ratio are necessary needed in order to decrease the energy loss with ventilation.

2) Factors and conditions to design the passive ventilation system

The airtight level of a house is one of the factors in realizing the passive ventilation system. The filtration has an influence on the balance of airflow rate in the heat exchanger and energy loss with ventilation. Fig.10 shows the ventilation rate and C means the equivalent leakage area per its floor area (cm^2/m^2). The ventilation rate decreases with the heat exchange ratio. Fig .11 shows the temperature of supply air. The temperature rises with the heat exchange ratio. In the case of 'C = 5', the temperature reaches the temperature of indoor air:20℃ because the supply air flow rate is 0(m^3/h). Fig.12 shows the energy loss with ventilation. The energy loss decrease with the heat exchange ratio. But the energy losses have a minimum limit because the air flows back through the air supply route in the heat exchanger in the case that the airtight level is low or the heat exchange ratio is high.

Fig.13 shows the relationship between the ventilation rate and the energy loss on condition that the air does not flow back in the heat exchanger. A_{sp} is the airflow ratio of an air supply route and it is the same as A_{ex}: that of air exhaust route. In the case of 'C=5'and 'A_{sp}=300', the heat exchange ratio is 0.17 and the energy loss with ventilation is 1.0 (kW). And 'A_{sp}=400' can not be selected. In the case of 'C=2'and 'A_{sp}=400', the heat exchange ratio is 0.73 and the energy loss with ventilation is 0.7 (kW). In the case of 'C=0' and 'A_{sp}=700', the heat exchange ratio is 0.81 and the energy loss with ventilation will be 0.3 (kW). These cases show that the demand level of airtight is expected to be

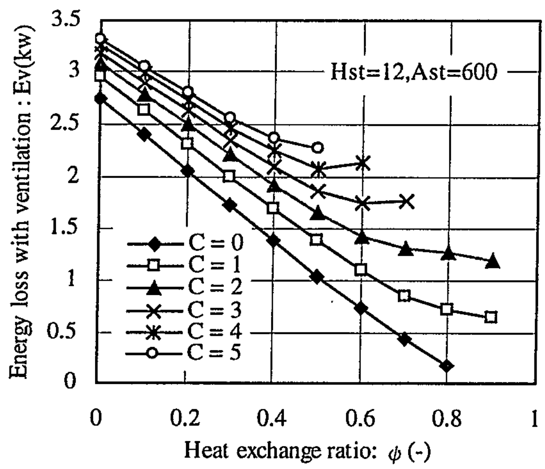

Figure 10 Heat exchange ratio and ventilation rate

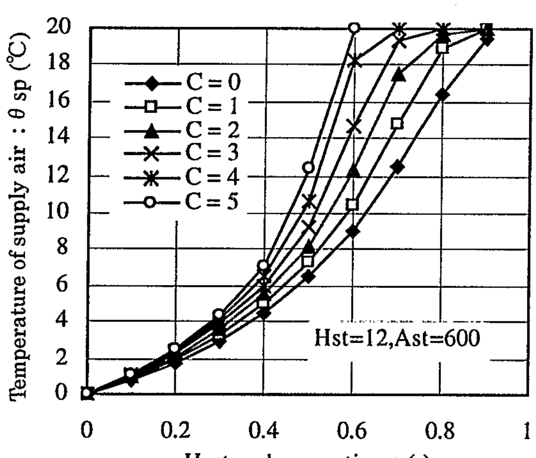

Figure 11 Temperature of supply air

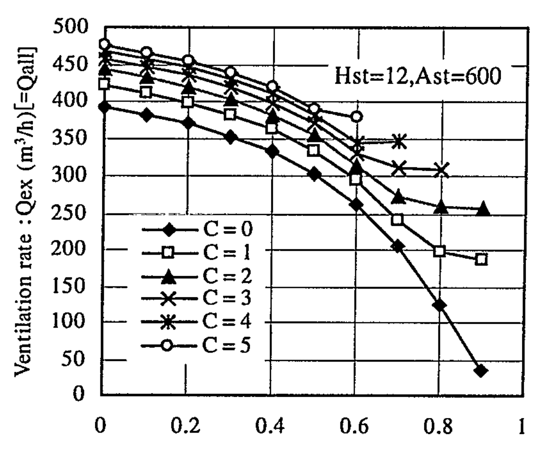

Figure 12 Energy loss with ventilation

very high in order to save energy.

Fig.14 shows the heat exchange ratios that make the ventilation rate meet the ventilation requirement when the maximum heat exchange ratio is 0.8. If the airflow ratios of the ventilation routes are large, the heat exchange ratios can be made to be large. These ratios must be decided considering the ventilation rate when the temperature difference is not large. So it is necessary to control the ventilation rate in the coldest season. One of the methods is using dampers. But a better method is that the heat exchange ratio is controlled to make the ventilation rate meet the ventilation requirement, because the energy loss will be lower. Fig.15 shows the change of the calculated energy loss with ventilation in the house of which equivalent leakage area is 0.5. The energy losses are calculated using the standard weather data of SAPPORO in Japan. In the case of 'ψ=0', a heat exchanger is not installed in the ventilation system and the ventilation rate is controlled with dampers. In the case of '0< ψ <0.8', a heat exchanger is installed and the heat exchange ratio is controlled as shown in Fig 14. The energy loss in the case of '0< ψ <0.8' decreases to 30% of that in the case of 'ψ=0' as shown in Fig.16.

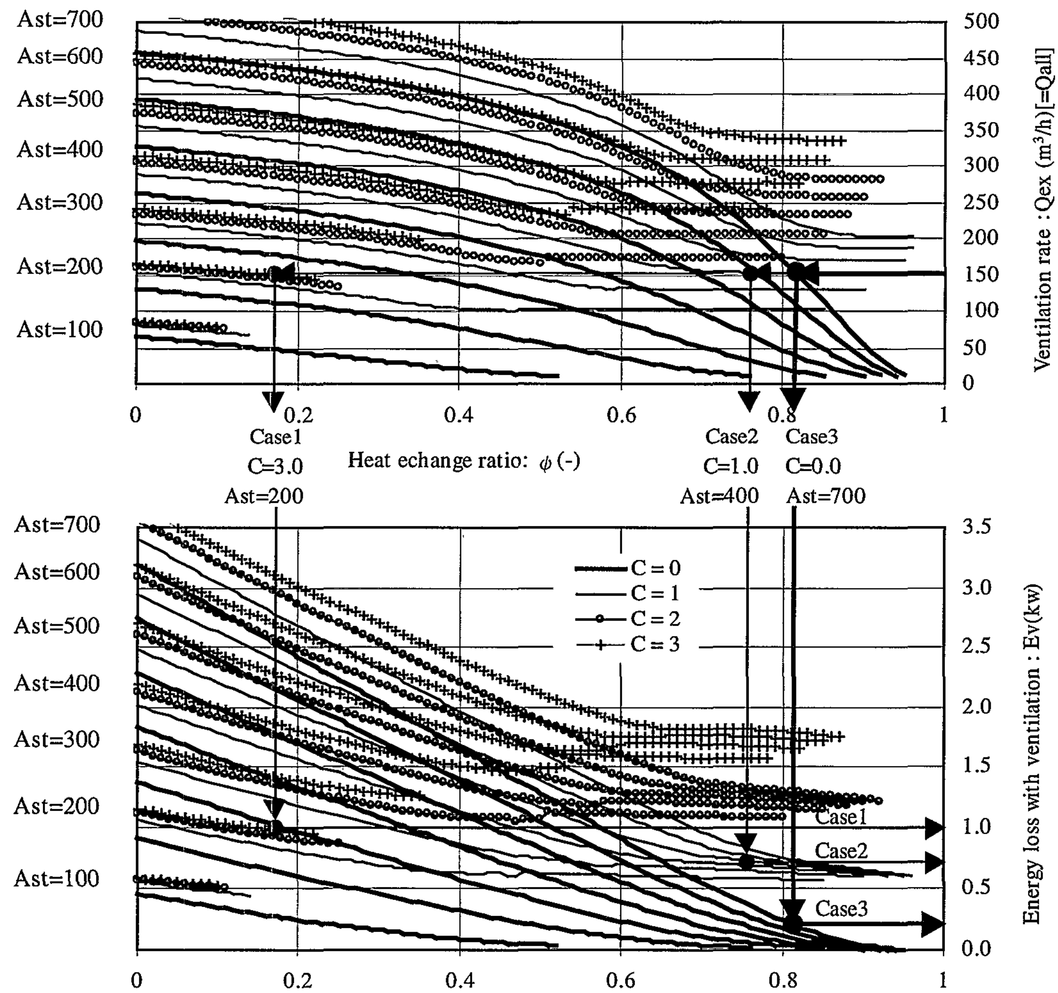

Figure 13 Relationship between ventilation rate and energy loss

DISCUSSION

These results showed the followings. The airtight of houses is indispensable to use the passive ventilation system with a heat exchanger. But the heat exchanger has a large effect on saving energy with ventilation. So, the authors expect that the system is most useful when installed in airtight houses in the cold region. In order to install the system in the houses, the following tasks must be investigated, the method to control the heat exchange ratio, the protection of the top of the stack against snow and rain, the maintenance and the suitable structure for the general houses.

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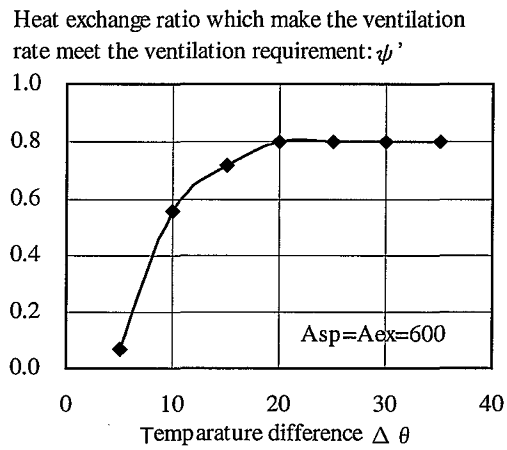

Figure 14 Suitable heat exchange rate

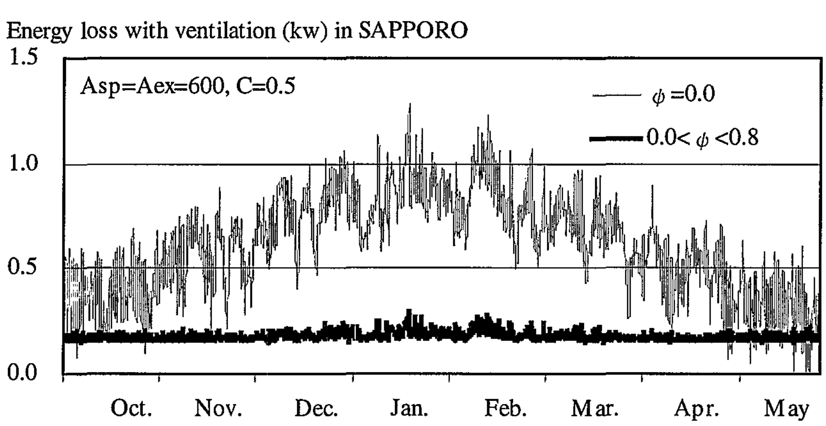

Figure 15 Change of energy loss with ventilation

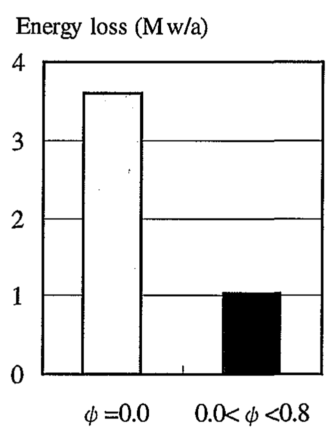

Figure 16 Effect of heat exchange