Performance Estimation of Window-Mounted Solar Heat Driven Ventilation System by Numerical Analysis

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SUMMARY

This research proposes a simple device added to a window. The device improves indoor ventilation using solar heat. It made from shoji paper, which is the traditional paper of Japan. The structure of the device is five air layers from five partitions of shoji paper. The device provides insulation. In summer, it is used for ventilation. In winter, it is used for insulation at night. Experiments were conducted with the device, and the ventilation performance and thermal insulation were confirmed. This paper reports the results of a numerical analysis of the device installed in a building model. The difference of climate regions and direction of the building were considered in the numerical analysis. The amount of ventilation and the room temperature of the building in six regions were confirmed.

INTRODUCTION

In recent years, various window systems such as Double-Skin and air ventilation windows have been developed with the intent to provide a comfortable indoor environment. These indoor environments have been designed with devices that block the outside environment from entering. As a result, rooms are airtight, highly insulated, and maintain a constant environment. However, one problem is that the devices are complicated. Here, a simple device using solar heat as the driving power of ventilation is proposed. It maintains indoor comfort using changes in the outside environment, as is similar to traditional Japanese construction.

METHODS

Outline of device

Figure 1 shows the designed fitting. It is made from shoji paper, which is the traditional paper of Japan. The structure of the device is five air layers created by the five shoji paper partitions. The multiple air flow of the five air layers due to the shoji paper partitions is installed. Figure 2 shows the principle of the device. Buoyancy is created by a decrease in the density in the air layers because of the solar heat gain from the outside. This chimney effect is used as the driving power of the ventilation. Indoor air is drawn by the chimney effect, and ventilation is created. The heat generated on the surface of the device is extracted before it reaches indoors. In summer, it is used for ventilation. Moreover, the device provides insulation when the air layers of the device are sealed up. The midair layers between the shojis do not transmit heat. Therefore, it can be used for insulation at nighttime in winter.
The performance of the device was confirmed by experiment. This experiment result was previously reported\(^1\). Table 1 a) shows the amount of ventilation to quantity of solar radiation and b) shows various overall heat transfer coefficient. A ventilation experiment was performed to verify the ventilation performance by measuring insolation and circulation. The amount of ventilation obtained by this device was 93 m\(^3\)/h. The calculation value was 80 m\(^3\)/h. Compared to the calculated value, the experimental value reached a higher value due to the external wind effect. The insulation efficiency of the device was examined to determine whether the performance was adequate for a house. The heat loss experiment was conducted according to the JIS\(^2\) standard. The overall heat transfer coefficient reached a low value of 1.63 W/m\(^2\)K. Moreover, it was a slightly smaller value than the value of general fittings. This may indicate that the number of shoji layers should be five in the production fitting to increase the thermal resistance of the air spaces. Therefore, it is thought that this device can be adjusted to most houses because the adiabaticity of the production fitting is more excellent than that of general fittings.

<table>
<thead>
<tr>
<th>Quantity of solar radiation [W]</th>
<th>Amount of ventilation [m(^3)/h]</th>
<th>Calculated value</th>
<th>Experiment value</th>
</tr>
</thead>
<tbody>
<tr>
<td>733</td>
<td>80</td>
<td>93</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.** a) Amount of ventilation. b) Various overall heat transfer coefficient.

<table>
<thead>
<tr>
<th>Heat transfer rate [W/m(^2)K]</th>
<th>Single window 3mm</th>
<th>Double glass window 12mm</th>
<th>Production fitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.00</td>
<td>3.40</td>
<td>1.63</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1.** View of device. a) Outside. b) Detailed cross section. c) Inside.

**Figure 2.** Chimney effect of solar heat.
Outline of simulation

The external wind effect was large in the ventilation experiment. The performance of the building model with the installed device was also estimated by a simulation. The performance of the building model was compared for different climate and azimuth conditions. Furthermore, the building models of various conditions were forecasted and the indoor thermal environment of the building models was evaluated.

Figure 2 is a cross section of the building model in the simulation. The floor, wall, and roof are completely insulated. The influence of the insulation heat and the outside temperature is given from the window. Here, the window side of the building model is the azimuth of the building model. The building model was turned to four azimuths facing the south, the north, the west, and the east for the analysis. The building model was analyzed for the weather of six typical areas. Japan is long and has different geographical features in the north and south. Therefore, the climate is greatly different according to the region (Figure 3).

Figure 4 shows the thermal and airflow network model. In the numerical analysis, the thermal and airflow network model simulation program NETS\textsuperscript{3)} was used.

Figure 3. a) Climograph. b) Analytical regions.

Figure 4. a) Thermal network model. b) Airflow network model.
RESULTS

Natural ventilation and thermal environment

Figure 5 a) shows the vertical temperature gradient in device and amount of ventilation. This figure shows the value of the building model facing the south in August in Tokyo. The amount of ventilation follows the temperature gradient. Therefore, ventilation due to the temperature gradient was confirmed. Figure 5 b) shows the outdoor and indoor temperature on the building model for all four azimuths. This figure shows the value of the building model in August in Tokyo. The room temperature of the model facing the east is the lowest, when there is a maximum amount of ventilation.

![Figure 5](image_url)

Figure 5. a) Temperature gradient and ventilation performance. b) Outdoor and indoor temperature.

Amount of waste heat

Figure 6 is the scatter chart of the amount of waste heat. This figure shows the value of the building model facing the south and the north in August in Tokyo. There are correlations in the waste calories and the quantity of solar radiation. Ventilation performance is improved when the solar radiation is high, because the amount of ventilation depends on the heat acquisition of the device. However, the amount of waste heat of the building model facing the north was calculated as 50% of that of the building model facing the south.

![Figure 6](image_url)

Figure 6. Amount of waste heat to quantity of solar radiation.
**Amount of ventilation**

Figure 7 a) shows the daily amount of total ventilation from April to November in Tokyo. The building model facing the north has a calculated amount of ventilation from 60% to 90% of that of the other azimuths models in each period. Figure 7 b) shows the daily amount of total ventilation in the six regions of Japan. The model building facing the north has a calculated amount of ventilation from 84% to 98% of that of the other azimuths models in the various regions. The difference of the amount of ventilation by the region of the building model was slight.

![Figure 7](image)

**Exhaust efficiency of device**

Figure 8 shows the relation of the exhaust efficiency to quantity of solar radiation in Tokyo. It is thought that the width of each air layer in device influenced the amount of ventilation from the result of amount of ventilation. Therefore, performance of the structure which made double of the width of second, third and fourth air layer was confirmed. The exhaust efficiency was calculated from the temperatures fluctuation of $T_a$ and $T_i$ and the temperatures fluctuate of $T_a$ and $T_o$ (Figure 2, (1)). The difference of the exhaust efficiency was slight, when the width of air layers is made wide. When the quantity of solar radiation exceeds 200 W/m², the inclination of the scatter chart becomes small. The exhaust efficiency reaches a maximum of 70% as the quantity of solar radiation increases.

![Figure 8](image)

**Exhaust efficiency [%]**

$$
\text{Exhaust efficiency [%]} = \left( \frac{T_a - T_i}{T_a - T_o} \right) \times 100, \quad (1)
$$
DISCUSSION

This paper next examines the efficiency of the ventilation system on the basis of the simulation results.

Performance of device

There are correlations in the amount of ventilation and the quantity of solar radiation. It was shown that the solar heat helped to drive the power of the ventilation. The amount of ventilation follows the temperature gradient. Therefore, natural ventilation was confirmed. In addition, the heat generated on the surface of the device was extracted by ventilation before it came indoors. Thus, the thermal insulation performance of the device was confirmed. However, the exhaust efficiency by ventilation reaches a maximum when the quantity of solar radiation exceeds 200 W/m$^2$. Therefore, the difference of the amount of ventilation in the six regions and the four azimuths was slight.

Design of device

The width of each air layer greatly influenced the amount of ventilation. Thermal resistance in the device is large. Therefore, it is necessary to review the design of the device. However, experimental results of the insulation performance may indicate that the number of shoji layers should be five in the production device to increase the thermal resistance of the air spaces. Therefore, the device is thought to have adjustability to various conventional houses.

This research proposes a simple device added to a window with function of ventilation and thermal insulation. The functions demanded from a window are light, view and ventilation. The proposed device must provide a secure, continuous structure from outside to inside. Therefore, the device that provides both ventilation and insulation efficiency was produced. The ventilation performance of the device using a natural resource and the insulation performance of the device using a natural material were confirmed. People will feel the positive effect from connecting to nature by using this device. The technology proposed here can be combined with traditional skills to create a new architectural style for future generations.

ACKNOWLEDGMENT

NETS is thermal and airflow network model simulation program developed by Dr. Okuyama H of Shimizu Corporation Institute of Technology. The author greatly appreciates the offer of NETS.

REFERENCES

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