AN EXPERIMENTAL STUDY ON AIRFLOW IN THE CAVITY OF A VENTILATED ROOF

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ABSTRACT

The thermal performance of the building envelope is mainly required for guaranteeing a comfortable and hygienic interior climate. A roof is a part of the building envelope which provides protection from the thermal damage of the sun. To improve this protection ability, we can consider using a ventilated roof, which has a ventilation layer known as a cavity, beneath the roof cover panel.

The objective of this study is to evaluate the influence of such factors as the slope of the roof, size or shape of the openings (i.e. inlet or outlet), effective cross section and cavity depth on the improvement of the air flow in the cavity for better thermal performance of the ventilated roof. In this study, the influence on air flow which is caused by the characteristics of these elements is researched. The evaluations are carried out by way of experiments.

KEYWORDS

Ventilated roof, Cooling loads, Cavity, Experiment

INTRODUCTION

To reduce environmental damage and pursue high quality indoor conditions in buildings, it is important to save energy. There are open discussions concerning how to improve energy performance in building envelopes. Building envelopes play a great role in solar heat gain because they contact with outdoor air directly. Especially, because the roof angle is almost vertical with the rays of the sun, the roof is liable to gain heats. In summer, the solar heat gain increases, and it overheat the roof. Therefore, heat transfers from outside to inside through the envelope and holds a great portion of the cooling loads. In low and large floor area buildings (e.g. factories or warehouses) which have broad roof areas, this could become even worse.

We have to minimize the cooling loads from solar heat gain. The demands to reduce the cooling loads in the building envelope are pushing designers into the application of a more active envelope system. One of the ideas about this active envelope system for protecting a building from the solar heat gain is to activate the natural convection on the roof. We can exhaust the heat by adding another layer-ventilation layer- on the roof. The absorbed solar energy from the roof will be transferred to the airflow by convection and the ventilated roof can decrease the cooling loads by preventing heat accumulation on the roof.

To improve these performances on the ventilated roof, various parameters could be considered in the

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design of a more efficient method of thermal performance. The objective of this study is to evaluate the thermal performance among such parameters as ‘sheet-bending type’, angle of the roof and heating temperature. The evaluation is mainly accomplished by way of experiments.

METHOD

Description of the experiments
To evaluate the thermal performance of the ventilated roof, the roof simulator was set up at the test center, Seoul, Korea for three weeks (23rd April ~ 14th May, 2007). The test center was kept in a constant temperature condition during this period by way of an HVAC system, which means the initial inlet air temperature of the cavity was constant. There is absolutely no air stream caused by the HVAC system, so the airflow on the cavity is caused only by the buoyancy force. The purpose of the experiment was to measure the temperature distribution at the cavity and airflow velocity at outlet of the cavity in the following cases, shown in Table 1. Through the temperature distribution and airflow velocity measurement, we could evaluate the exhausted heat from the cavity.

Test number and parameters
The ventilated roof panel is devised at three kinds by the shape of the cavity. Figure 1 shows the section of the roof panel. The flat sheet is a ventilated roof that has a cavity depth of 30 mm. It has a 30 mm ventilated layer on the urethane foam. The profiled sheet is a type of roof sheet that considers structural stability and constructability and that has a cavity for ventilation. The cavity shape of the profiled sheet is 90 x 30 mm [(width) x (depth)] and 90 x 60. Figure 2 shows the elevation of a roof panel with a cavity. As shown in Table 1, the test was conducted by a bending type or shape of cavity, roof angle, heating temperature, and cavity ventilated or non-ventilated. The Test No.1 shows the thermal performance as “Bending type or Shape of the cavity” which means the 30 mm of the flat sheet and the 90 x 60 mm of the profiled sheet. The Test No. 2 shows the thermal performance as “Angle of roof” changes from 0° to 55°. The Test No. 3 was conducted to find the thermal performance as “Heating temperature” changes from 55°C to 75°C. Finally, we could find the priority between the non-ventilated roof and the ventilated roof in Test No. 4.

Table 1 The parameters of the roof panel on test

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Parameters</th>
<th>Bending type</th>
<th>Shape of cavity (C_L x C_D) [㎜]</th>
<th>Angle of roof [˚]</th>
<th>Heating Temp. [℃]</th>
<th>Cavity open or close</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bending type</td>
<td>Flat sheet</td>
<td>(null) x 30 90 x 60</td>
<td>55</td>
<td>65</td>
<td>Open</td>
</tr>
<tr>
<td>2</td>
<td>Angle of roof</td>
<td>Profiled sheet</td>
<td>90 x 30</td>
<td>0</td>
<td>65</td>
<td>Open</td>
</tr>
<tr>
<td>3</td>
<td>Heating Temperature</td>
<td>Profiled sheet</td>
<td>90 x 30</td>
<td>55</td>
<td>65 75</td>
<td>Open</td>
</tr>
<tr>
<td>4</td>
<td>Cavity open(ventilated) and close(non-ventilated)</td>
<td>Profiled sheet</td>
<td>90 x 60</td>
<td>55</td>
<td>65</td>
<td>Open, Close</td>
</tr>
</tbody>
</table>
The roof simulator

The roof simulator is consisted of:

- Heating Panel (which simulates the solar heat gain)
- Roof Panel (an object to evaluate)
- Chamber (which simulates under room of the roof)
- Heating and Cooling Unit (which keeps the temperature of the chamber constant)

As shown in Figure 3, the roof simulator simulates a small-scaled room with a ventilated roof. It is consisted of the heating panel, the roof panel, the chamber and the heating and cooling unit. The roof panel on the chamber could change to another one. It could change the roof angle from 0° to 90° by way of hydraulic drive cylinder, as shown in Figure 4. The chamber was kept at a constant temperature.
by the heating and cooling unit. Because the ventilated roof used in this study is for large-scale buildings, the constant temperature below the roof is about 28.0 °C. The chamber is relatively small compared with real buildings, which means that it is possible that the temperature distribution is irregular. So, the deflector is installed to obtain uniform air distribution in chamber.

The heating panel which simulates the solar heat gain is composed of the heating coil element and the glass wool. The aluminum panel (thickness: 2 mm) beneath the heating panel disperses the temperature evenly and the urethane foam (thickness: 50 mm) above the heating panel blocks the heat from going upward.

To evaluate thermal performance in summer, the temperature distribution is measured at the roof panel and the chamber while the heating panel is at work. Also, to estimate the amount of heat exhausted via the cavity, the velocity of the air flow is measured. Both sides of the roof panel are insulated by the urethane foam panel, since the roof panel would extend in both directions in a real situation.

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The equilibrium of the system

When the heating panel starts to work, the temperature of the heating panel and the chamber are increased. The chamber should be cooled by the heating and cooling unit so that the temperature inside the chamber can be maintained at a constant level. Therefore, stabilization was performed until the whole system achieved equilibrium. As shown in Figure 5, this process takes about 60 minutes when the temperature reaches a constant temperature (28.0 °C) condition after which the measuring begins.

![Figure 5](image)

Figure 5  The stabilization of the system

The temperature distribution in the cavity has to be measured to check the thermal flow. The temperature of the section of each surface is measured. In addition the velocity of the air flow has to be measured at two points to evaluate the exhausted heat. After confirming the stabilization, the temperature is recorded every two minutes at each point over a period of 180 minutes. The velocity of flow is recorded at each point of the inlet and the outlet of the cavity after 60 minutes (the time when the stabilization is completed). It is sufficient to confirm that the data is stable.

**Evaluation**

We can analyze the thermal performance of the ventilated roof by estimate the exhausted thermal load. It could be found by equation (1).

\[
Q_{\text{out}} = m \cdot c_{p} \cdot (T_{\text{out}} - T_{\text{in}}) \quad \text{[kW]} \tag{1}
\]

- \(Q_{\text{out}}\) = amount of exhausted heat via the cavity
- \(T_{\text{in}}\) = inlet temperature
- \(T_{\text{out}}\) = outlet temperature
- \(c_{p}\) = specific heat of air

In this study, we can consider the \(Q_{\text{out}}\) or exhausted heat as the thermal performance, because the \(Q_{\text{out}}\) reflects the \(m\), \(V\) and the temperature difference between the inlet and the outlet of the cavity.
RESULT and DISCUSSION

[Test No 1] 30 mm flat sheet and 90 x 60 profiled sheet

As shown in Figure 6 (a), the temperature difference between the inlet and the outlet of the flat sheet's cavity is 5.7°C and that of the profiled sheet is 10.4°C, which is higher than the flat sheet. Figure 6 (b) shows the profiled sheet is revealed to have priority in thermal performance of about six times in the cooling season compared to the flat sheet, which has the same effective ventilated area. The temperature distribution in the cavity is shown in Figure 6 (c). The profiled sheet shows a lower temperature range at the cavity.

[Test No. 2] 90 x 60 profiled sheet at a angles of 0°°°°, 25°°°°, 40°°°° and 55°°°°

As shown in Figure 7 (c), the cavity temperature of 65°C is almost the same as the temperature of the heating panel when the angle of the roof is 0°. However, when the roof is angled, the air flow develops. So the temperature of midpoint of the cavity goes down, decreasing to 40.3°C when the roof has an angle of 55° as shown in Figure 7 (a). When the angle of the roof goes deeper, thermal performance becomes relatively high. In the steepest case (55°), it seems that the buoyancy force develops well. Because the air flow velocity rises as the roof angle increases, the exhausted heat increases as well.
The exhausted heat at each angle is shown in Figure 7 (b). The exhausted heat has increased from 178 W to 286 W.

[Test No. 3] 90 x 30 Profiled sheet at temperatures of 55°C, 65°C and 75°C

In the case where the heating temperature is 55°C, the cavity temperature shows to be about 37.1°C, as shown in Figure 8 (C). The temperature of the midpoint of the cavity is 40.0°C when the heating temperature is 75°C. When the heating temperature increases, the temperature difference and the amount of heat exhausted are also increased. The exhausted heat has increased from 188 W to 367 W as shown in Figure 8 (b).

[Test No. 4] 90 x 60 Profiled sheet when the cavity is open or closed

This part of the analysis shows the priority of the ventilated roof in cooling performance. When the cavity is closed, the temperature of the cavity rises to almost the same temperature as that of the heating panel (about 65°C, as shown in Figures 9 (a) and (c)). Yet, once the cavity is open, the airflow is produced. The temperature of the midpoint of the cavity drops to 27.5°C. Theoretically, there is no airflow when the cavity is closed and no heat exhaust occurs, as shown in Figure 9 (b).
CONCLUSION

The summary of this study is as follows:

- A ventilated roof has a priority in air flow velocity and thermal performance compared to a non-ventilated roof. When making a ventilated layer on a common roof (non-ventilated roof), we can prevent thermal accumulation on the roof.

- In a flat sheet ventilated roof, air flow velocity and thermal performance goes down due to the uncertainty of thermal path. So, a profiled sheet ventilated roof is recommended.

- As the temperature of the heating panel increases, air flow velocity and the thermal performance of the ventilated roof improves, which means that the ventilated roof is used more effectively in the area where the solar heat is intense.

- It has been proved that the steeper the angle of a pitched roof is, the better the air flow velocity and the thermal performance is. Since the constructor cannot lift the slope of the roof without limitation, the additional work of finding proper angle should be performed only after comparing it with other factors.

REFERENCES