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AN EXPERIMENTAL VERIFICATION OF INFLUENCING FACTORS ON THE MECHANISM OF HEAT TRANSFER IN THE CAVITY ROOF VENTILATION

Abstract: *The roof, as a part of the building envelope with the thermal performance that's a major requirement for guaranteeing a comfortable and hygienic interior climate, provides protection from thermal damage incurred by the sun. To improve this protection ability, the use of a ventilated roof can be considered, which has a ventilation layer known as a cavity, beneath the roof cover panel. Based on the proposed mechanism of heat transfer and the influence of such factors as cavity ventilation, the slope of the roof, intensity of solar radiation, the size and shape of the cavity, and panel profiles, airflow and temperature distribution are analyzed in the cavity, in an effort to improve the cooling effect of ventilation in the cavity of the roof. In this study, the influence of these elements on airflow is studied.*

Key words: temperature distribution, cooling effect, air flow, thermal comfort, ventilation channel.

INTRODUCTION

There is a growing awareness regarding the need to reduce energy consumption and to improve indoor environment quality, and accordingly, the energy performance of a building envelope is becoming more and more important. Building envelopes play a major role in solar heat gain, because they are in direct contact with outdoor air. In a conventional construction, the surface temperatures of a building envelope can easily reach 75–80 °C, depending on the orientation, tilt and the time of year [1]. It is also important to minimize the cooling loads from solar heat gain.

In summer, because of the significant increase in solar heat gain via the roof, heat transfer from the outside to the inside through the roof occupies a great portion of the cooling load. This heat can be discharged by adding another layer - a ventilation layer - in the roof. Thus, the absorbed solar energy from the roof will be transferred to the airflow induced by convection and the ventilated roof can decrease the cooling load by preventing heat accumulation in the roof.

MECHANISM OF HEAT TRANSFER IN A VENTILATED ROOF

Roofs can generally be divided into two types: warm roofs and cool roofs.Warm roof designs are configured with each component of the roof assembly placed in contact with the preceding component as in Fig. 1(a). Cool roof designs are configured with the insulation located below the deck, allowing for a ventilation space. In a cool roof, the cavity for ventilation is generally located in the space above an insulated ceiling assembly and below the deck, as in Fig. 1(b). Sometimes, the cavity of a cool roof is closed, to be protected from weather exposure. Fig. 1(c) shows a cool roof with a non-ventilated cavity.

This paper provides results of experiments performed on roofs that include cavities: a ventilated roof and a non-ventilated roof, under summer conditions. The reason for ventilation is based on the assumption that outdoor air passing through a roof will, in average, cool the structure over time.

The balance of heat transfer in a ventilated roof, as shown in Fig. 2, includes conductive heat transfer from the outside to the inside due to temperature difference across the roof, radiation heat gain from the outer surface, together with convective heat transfer, when outdoor air passes through the ventilated cavity [2]. We analyzed the thermal performance of the ventilated roof by estimating the amount of exhausted heat by the following Equation (1):

$$Q_{SO}=Q_{out}+Q_V \tag{1}$$

where

Q_{SO} is the heat gain from solar radiation (W),

Q_{out} is the heat flow back to the outside (W),

Q_{in} is the heat flow to the interior (W),

Q_V is the exhausted heat via the cavity (W) and is given by

$$Q_v = \dot{m} c_p (T_{out} - T_{in}), \tag{2}$$

where

$\dot{m}$ is the mass flow rate (kg/s),

c_p is the air specific heat at constant pressure (J/kgK),

T_{out} is the outside air temperature in the shade (K),

T_{in} is the indoor air temperature (K).

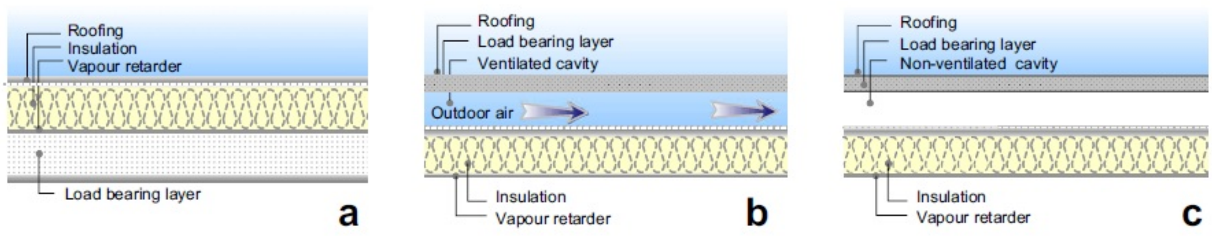

Figure 1. *Roof types according to configuration of roof components. (a) Warm roof. (b) Cool roof with ventilated cavity. (c) Cool roof with non-ventilated cavity.*

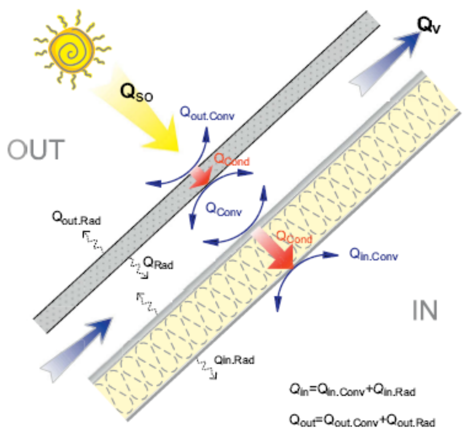

Figure 2. *Mechanism of heat transfer in a ventilated roof*

ROOF-SIMULATOR

The temperature distribution in the cavity was measured to check the temperature difference between the inlet and the outlet. The airflow velocity was measured at the outlet to evaluate mass flow rate. Through the temperature distribution and airflow velocity measurements, we estimated the exhausted heat flux from the cavity as the thermal performance of the ventilated roofs. If the heat flux from the cavity to the outside [Q_v] is increased, heat flow from the cavity to the interior [Q_{in}] would be decreased [3].

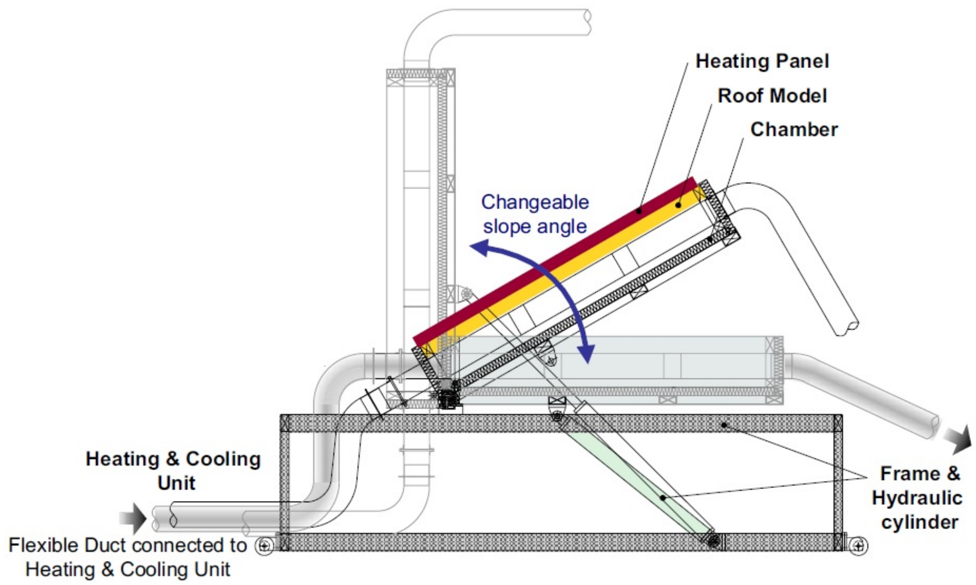

Figure 3. *Schematic view of the Roof-simulator*

A series of tests were carried out using the Roof-simulator [4]. To compare the performance of various roofs which have different types of cavities under the same conditions, the Roof-simulatorwas designed. The Roof-simulator consists of:

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

The heating panel which simulates the solar heat gain is composed of a metal lid, glass wool, a gypsum board, a heating foil, and an aluminum plate. The aluminum plate (thickness: 2 mm) beneath the heating foil disperses heat evenly to make the heat flux to the roof panel uniform, and the glass wool (thickness: 50 mm) above the heating foil blocks the heat flux directed upward. The heating panel controls the surface temperature of the roof model.

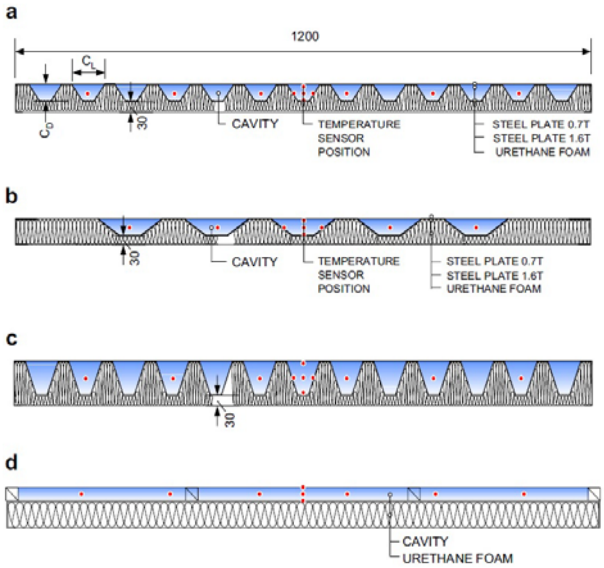

Figure 4. *Horizontal sections of the roof models. (a) The roof model with ribbed panel having a cavity size of 90 mm [C_L] x 30 mm [C_D]. (b) The roof model with ribbed panel having a cavity size of 180 mm x 30 mm. (c) The roof model with ribbed panel having a cavity size of 90 mm x 60 mm. (d) The roof model with flat panel having a cavity size of (null) mm x 30 mm*

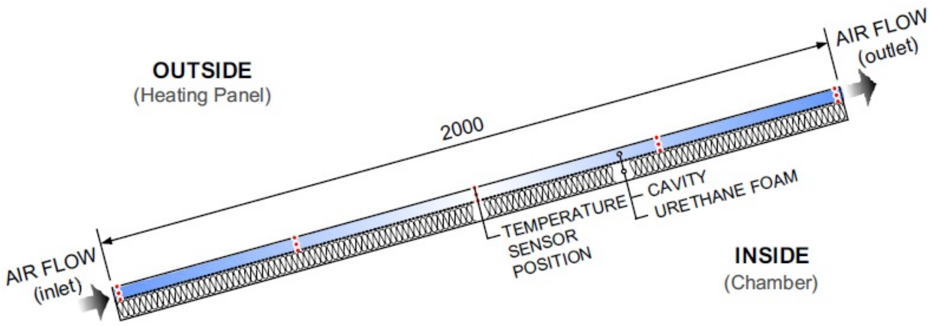

Figure 5. *Vertical section of the roof model*

The testing facility was air-conditioned during the experiments by an HVAC system, so that the temperature of influent air to the cavity was constant. There is no air stream caused by the HVAC system, so the airflow in the cavity is caused only by the buoyancy force.

Measurements were taken of temperatures and air velocity for the roof models in the Roof-simulator. Temperatures were measured with T-type thermocouples, which have a temperature range of -65 °C -130 °C and an error range of ±0.5 °C. The points of temperature measurement were placed at five positions from the inlet to the outlet of the cavity, to obtain temperature variation along the airflow path. To measure temperature distribution at the surfaces of a cavity, thermocouples were inserted in the middle cavity. The red spots in Figs. 4 and 5 indicate the positions of the temperature sensors.

Air velocity was measured using which is a high-precision multifunctional instrument. Because the cavitywas enclosed by metal, it could be assumed that therewas no airflow into the chamber. In a cavity having a uniform section area, if all of the airflow entering the cavity is made to flow out through the outlet of the cavity, air velocity will be same everywhere in the cavity. Therefore, only the air velocity at the outlet of the cavity was monitored.

The temperature difference between the inlet and the outlet and the air velocity at the outlet were used to estimate the heat flux along the cavity, and the temperatures of each surface of the cavity were monitored to investigate heat flux to the indoors. A preparatory test was performed to stabilize the temperature of the roof panel and the chamber. When the heating panel started to work, the temperature of the heating panel slowly increased. After air-conditioning by heating and cooling unit, the temperature in the chamber was maintained at a constant level.

RESULTS AND DISCUSSION

Slope of the roof

As shown in Fig. 6(c), the cavity temperature of 65 °C was almost the same as the temperature of the heating panel when the slope of the roof was at an angle of 0°. However, when the slope of the roof was steeper, an airflow was developed. The temperature at the middle cavity dropped to 40,3 °C, when the slope of the roof had an angle of 55°, as shown in Fig. 6(a). The airflow velocity and temperature difference were increased, the more the roof angle was increased, and the amount of exhausted heat became relatively higher due to the effect of the buoyancy force. The exhausted heat at each angle is shown in Fig. 6(b). The exhausted heat increased from 178W to 286W. Thus, a minimum angle is required when the ventilated roof is applied to produce a buoyancy force. This experiment did not, however, consider the effect of cavity length. In real situations, it must be considered that the total path and resistance of the cavity may be increased.

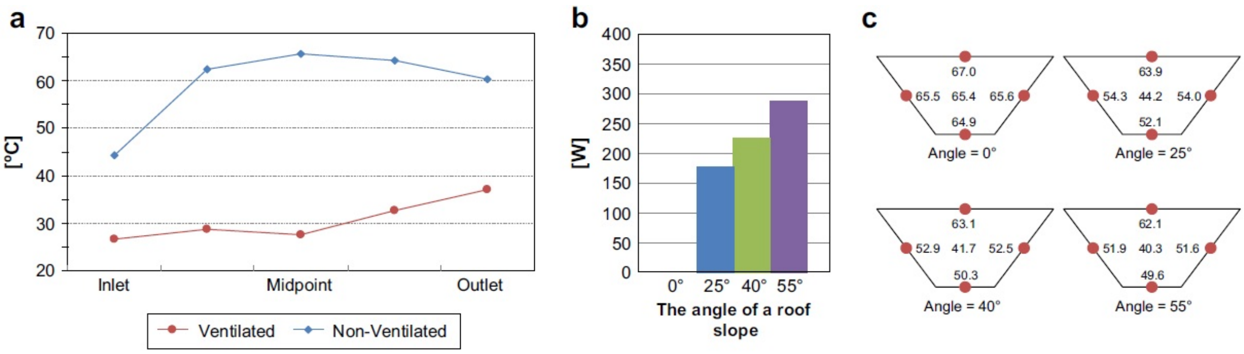

Figure 6. *Experimental results for the slope difference of roofs. (a) Temperature variation in cavity. (b) Exhausted heat from a cavity. (c) Temperature distribution in the middle cavity [°C]*

Intensity of solar radiation

In the case where the heating temperature was 55 °C, the cavity temperature was shown to be about 37,1 °C, as shown in Fig. 7(c). The temperature at the middle cavity was 40,0 °C when the heating temperature was 75 °C. When the heating temperature was increased, the temperature difference and the amount of heat exhausted were also increased. The exhausted heat was increased from 188W to 367W in Fig. 7(b). The temperature of the roof surface rises in proportion to the solar heat gain, and thus the ventilated roof can be useful where the solar heat gain is relatively high.

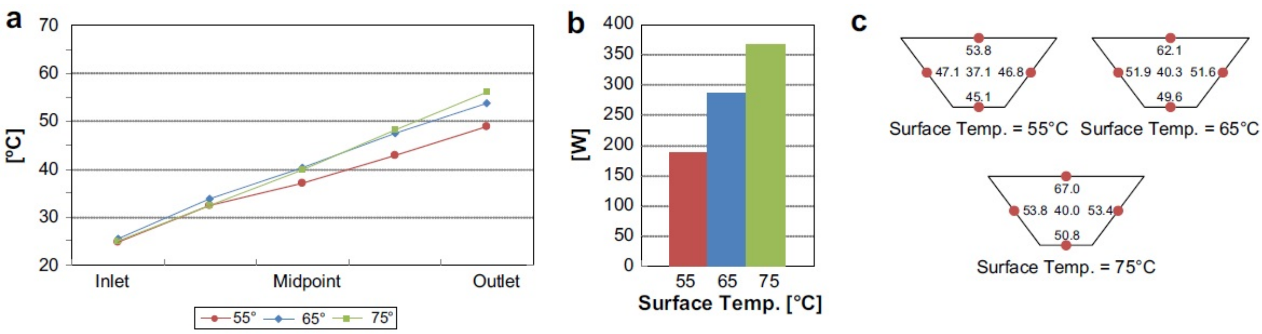

Figure 7. *Experimental results for the surface temperature difference of heating panels. (a) Temperature variation in cavity. (b) Exhausted heat from a cavity. (c) Temperature distribution at the outlet of cavity [°C]*

Cavity width

To analyze the effect of cavity width on thermal performance, the 90 mm x 30 mm cavity was compared with the 180 mm x 30 mm cavity, where the width of the cavity was doubled. The temperatures in the cavities increased similarly from the inlet to the outlet. The temperature difference between the inlet and the outlet was 28,2 °C for the 90 mm x 30 mm cavity and 22,7 °C for the 180 mm x 30 mm cavity, as shown in Fig. 8(a). The air velocity at the outlet of the 90 mm x 30 mm cavity was 0,47 m/s, while it was 0,5 m/s for the 180 mm x 30 mm cavity. Therefore, the exhausted heat of the 90 mm x 30 mm cavity was more than that of the 180 mm x 30 mm cavity; the exhausted heat being 286W for the 90 mm x 30 mm cavity and 172W for the 180 x 30 mm cavity, as shown in Fig. 8(b).

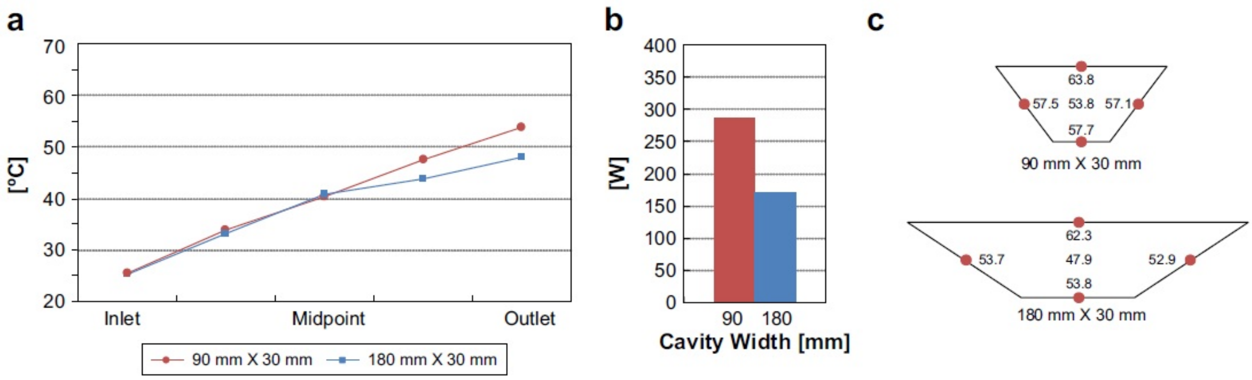

Figure 8. *Experimental results for the width difference of cavities. (a) Temperature variation in cavity. (b) Exhausted heat from a cavity. (c) Temperature distribution in the middle cavity [°C]*

While the surface temperatures of the cavities were similar to each other, the surface temperatures at the outlet of cavity for the 90 mm x 30 mm cavity were higher than those for the 180 mm x 30 mm cavity. The reason why the surface temperatures of the 90 mm x 30 cavity were higher, as in Fig. 8(c), is estimated to be because the shorter length of the perimeter promoted heat conduction and the closer surfaces transferred more radiant heat to one another. High surface temperatures speed up the airflow in cavity, so that the exhausted heat is increased. Therefore, to exhaust heat from cavity, effectively.

Cavity depth

Fig. 9 shows temperature distribution and the tendency of the exhausted heat for different depths of the ribbed panel. The temperature difference between the inlet and the outletwas greater for the 90 mm x 30 mm cavity than for the 90 mm x 60 mm cavity, as shown in Fig. 9(a). The temperature difference for the 90 mm x 60 mm cavity was 10,4 °C. Also, the air velocity at the outlet was 0.47 m/s for the 90 mm x 30 mmcavity and 0.61 m/s for the 90 mm x 60 mm cavity.

It can be considered that lower temperature in the 90 mm x 60 mm cavity was due to low surface temperatures and high air velocity. The low surface temperatures of the 90 mm x 60 mm cavity in Fig. 9(c) were because the heat transfer by conduction and radiation between each of the surfaces was less than those for the 90 mm x 30 mm cavity, because of cavity size. Also, the larger the cavity section area, the less the effect of friction resistance for airflow in the cavity. Therefore, it can be estimated that larger section area of the 90 mm x 60 mm cavity increased air velocity in the cavity.

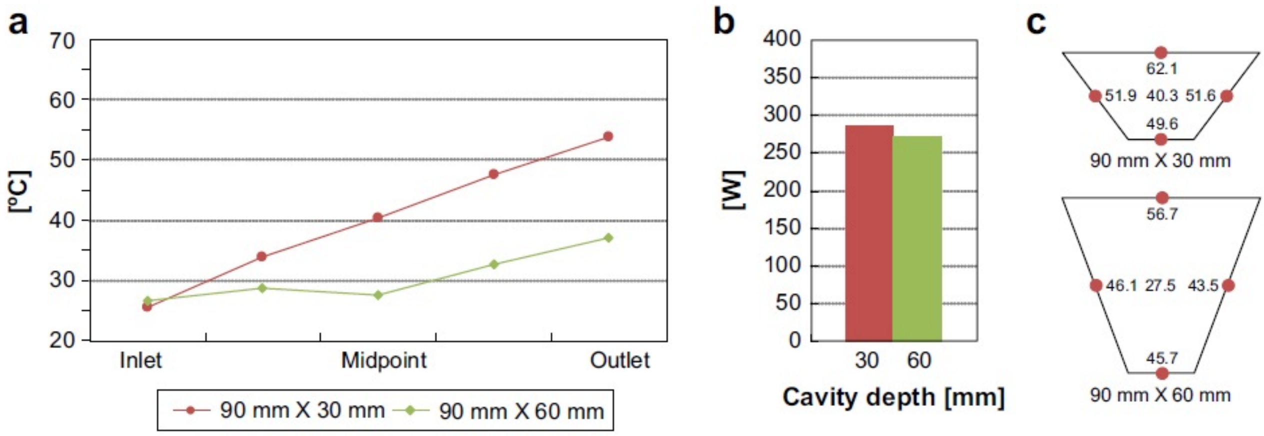

Figure 9. *Experimental results for the depth difference of cavities. (a) Temperature variation in cavity. (b) Exhausted heat from a cavity. (c) Temperature distribution in the middle cavity [°C]*

As shown in Fig. 9(b), the two cases are similar with regards the exhausted heat from a cavity. The amount of exhausted heat was 286W for the 90 mm x 30 mm cavity and 274W for the 90 mm x 60 mm cavity. The similarity in exhausted heat can be because the 90 mm x 30 mm cavity had a large temperature difference, while the 90 mm x 30 mm cavity indicated a higher air velocity.

Shape of a cavity

As shown in Fig. 10(a), the temperature difference between the inlet and the outlet of a roof having a ribbed panel was 10,4 °C and that of a roof having a flat panel was 5,7 °C. The air velocity for the case of the ribbed panel was also much higher than for the flat panel; 0.61 m/s for the ribbed panel and 0.22 m/s for the flat panel. The ribbed panel is thus revealed to have superiority in thermal performance compared to a flat panel having the same effective ventilated area. The ribbed panel showed higher surface temperatures in a cavity compared to the flat panel, as shown in Fig. 10(c), because of the conduction through the ribbed panel forming the cavity. It seems the higher surface temperatures promote airflow in the cavity. In consequence, the amount of exhausted heat from a cavity in the ribbed panel was much larger than that in the flat panel, as shown in Fig. 10(b).

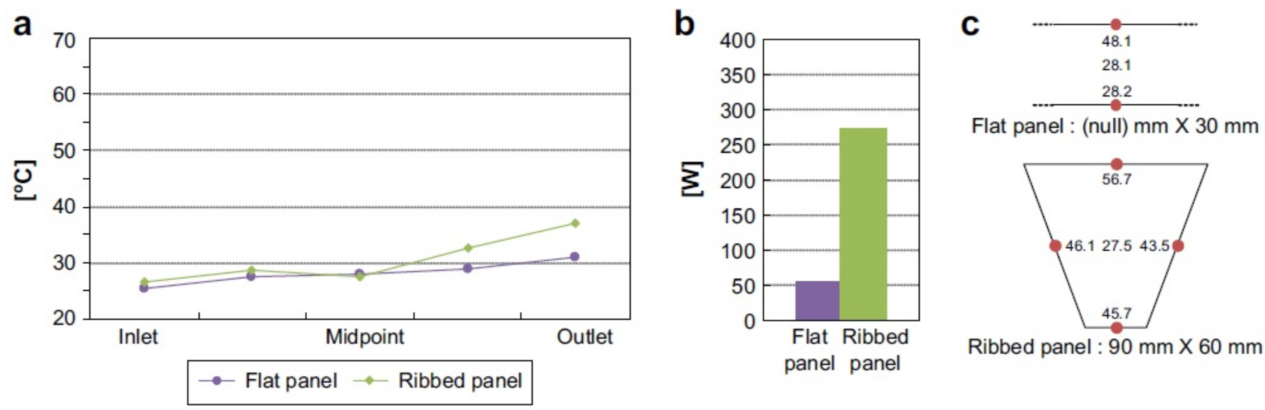

Figure 10. *Experimental results for the figure of a cavity. (a) Temperature variation in cavity. (b) Exhausted heat from a cavity. (c) Temperature distribution in the middle cavity [°C]*

CONCLUSION

By employing a ventilated layer in the roof, thermal accumulation in the roof can be prevented, and cooling load can be decreased. When the roof angle and the shape of a cavity are the same, increasing the surface temperature of the roof can improve the insulation performance of the ventilated roof. This means that the ventilated roof is useful where the solar heat gain is high. It has been proven that the steeper the slope of the roof, the lower the cavity temperature, when other parameters are the same. The additional work of finding a proper angle should be performed only after comparing it with other factors such as the direction of the roof and the region of the building. It is necessary to obtain a sufficient cavity depth and width to develop airflow velocity. In the case of the ribbed panel, the temperature of the lower surface of a cavity is high, because of conduction through the ribbed metal panel. Thus, a device serving as a thermal breaker has to be installed to prevent conduction.

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BIOGRAPHY

Dragana Temeljkovski was born in Niš, in Serbia, in 1987. She graduated from University of Niš, Faculty of Civil Engineering and Architecture. She is PhD student at Departmant of Energy and Process Engineering, Faculty of Mechanical Engineering in Niš, University of Niš. She published papers in the country and abroad and took part in Reginoal Workshops, International Conferences in Serbia and abroad. Her main areas of research include Energy and Process Engineering and Energy Efficiency.

EKSPERIMENTALNA VERIFIKACIJA UTICAJNIH FAKTORA NA MEHANIZAM PRENOSA TOPLOTE U ŠUPLJINI VENTILACIONOG KROVA

Dragana Temeljkovski

Apstrakt: *Krov, kao deo omotača zgrade sa svim svojim termalnim karakteristikama koje utiču na termalni komfor unutrašnjosti zgrade, omogućava zaštitu od termalnih oštećenja, uzrokovanih uticajem sunca. U obzir uzimamo upotrebu ventilacionih krovova, sa ventilacionim slojem poznatim kao kanalom koji je pozicioniran direktno ispod krovnog pokrivača, kako bi poboljšali mogućnost zaštite od temalnih oštećenja. Na osnovu predloženog mehanizma prenosa toplote i uzimajući u obzir faktore kao što su, ventilacioni kanal, nagib krova, intezitet solarne radijacije, veličina i oblik kanala, i vrste panela, analiziran je proces protoka vazduha i distribucije temperature u kanalu sa ciljem poboljšanja efekta hlađenja i ventilacije u kanalu krova. U ovom radu je razmatran uticaj ovih elemenata na strujanje vazduha.*

Ključne reči: distribucija temperature, efekat hlađenja, protok vazduha, termalni komfor, ventilacioni kanal.