Natural Ventilation of Attic Space for Solar Heat Removal - Heat and Air Flows along Lower Surface of a Roof

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ABSTRACT

In a hot climate, a large amount of solar heat irradiates on a roof, and it is transmitted to an occupied space beneath it through an attic. To interrupt this heat to attain a comfortable condition in the occupied space, ventilation of the attic is an important and effective measure. There are two ways of the ventilation, one is natural and the other is forces ventilation. The former measure should be considered prior to the latter from such reasons as simplicity in practice and power saving. Even though forced ventilation is applied, the natural air movement in the attic should be known to attain intended effect in forced ventilation.

In this study, the air and heat movements by natural convection were searched for with two electrically heated plates in a laboratory. The heat flux on the surface, incline angle of the plates and aperture on the top joint of the plates were variables in the experiments.

The velocity and temperature measurement and flow pattern observation indicated that an aperture of an 50 mm or above this is required to evacuate the heat absorbed air and to cool the lower surface of a roof effectively.

KEYWORDS

Air flow pattern, full-scale experiment, Natural ventilation, Plumes

INTRODUCTION

In areas of low to middle latitude, attic ventilation is a conventional measure to lessen radiation from the ceiling to the occupied space for thermal comfort and for cooling load reduction. Two measures, natural and forced ventilation are applicable for attic ventilation. But the former should be considered prior to the latter from the following two reasons. Firstly, the buoyancy of the air in an attic seems to have sufficient force to cause natural ventilation of an attic. Secondly, forced ventilation should be avoided, or be applied subsidiary, to make a house simple, and to avoid power consumption.

The natural ventilation has long been used, but its detail is not known well. When the nature of air and heat flows along an lower surface of a roof is known better, attic ventilation can be practiced more effectively. Further, the detailed knowledge of natural ventilation will increase the effect of forced ventilation.

In this study, the nature of air movement by buoyant force along lower surfaces of heated plates was studied in a laboratory experiment using two electrically heated plates. In the first part of this study, the character of the air and heat flows under an inclined single plate was examined in details. In the second experiment, two heated plates were arranged to form a triangle, leaving an aperture at the top joint. The conditions of the flow confrontation or enforcement of the two natural convections from the two sides were discussed. In the third experiment, a chimney was attached above the aperture. In this experiment, it was intended to know if the ventilation is encouraged or discouraged by the addition of a chimney.

EXPERIMENTAL ARRANGEMENT

The heat transmission from the lower surface of a roof to attic space was simulated by electrically heated plates of a width of 0.4m and a length of 2.4m. The heat production was controlled by electric power supply to them. The structure of the heated plates was reported elsewhere, refer to [Yamamoto et al.(1996.12)].

In the first experiment, one of the heated plate was hung in a laboratory with inclination angles changing from 5 to 45degrees from horizontal, facing the main heat dissipating surface downward. And the velocity and temperature distributions in the natural convection along the heated surface were measured.

In the second experiment, the two heated plates were arranged to form an attic triangle. The angle of inclination and the aperture at the top joint of the two plates were varied. The velocity and temperature distributions in the upper part of the triangle and in the natural convection plume were measured. The examined incline angles were 30 and 45 degrees. The examined apertures were 10,20,50 and 100mm. The combinations of examined heat productions on the left and right plates were (150-150), (150-100), (150-50), (100-100), (100-50) and (50-50W/m^2). The velocity and temperature distributions in the upper part of the triangle and in the natural convection plume were measured. The arrangement of the experimental set-up, including the traverse positions of the velocity and temperature measurement, is shown in figure 1.

In the third experiment, a chimney of the same section to the aperture and various heights were mounted on the aperture, and the influence of the chimney on the heat removal was examined. The examined heights of the chimney were 100,500 and 800mm.

The velocity were measured with two anemometers. One of which was a constant temperature hot wire anemometer, the probe of which was a tungsten wire of a diameter of 5 micrometers and a length of 1mm. The other anemometer was a hot sphere anemometer. The temperature was measured with copper-constantan thermocouples. For the velocity and temperature distribution measurement, the velocity and temperature probes were mounted on a traverse equipment, and the positioning and measurement were controlled according to an sequence, which was programmed in a small computer. In advance to the measurements, temperature distribution in the plume above the aperture was also observed with an infrared camera by hanging a sheet of paper in the plume. The flow patterns were also observed with a smoke wire technique.

RESULTS

Results of experiment 1

An example of the air velocity change along the center line is shown in figure 2. This is attained from an experiment of a convection heat flux of 46W/m^2, and an incline angle of 25

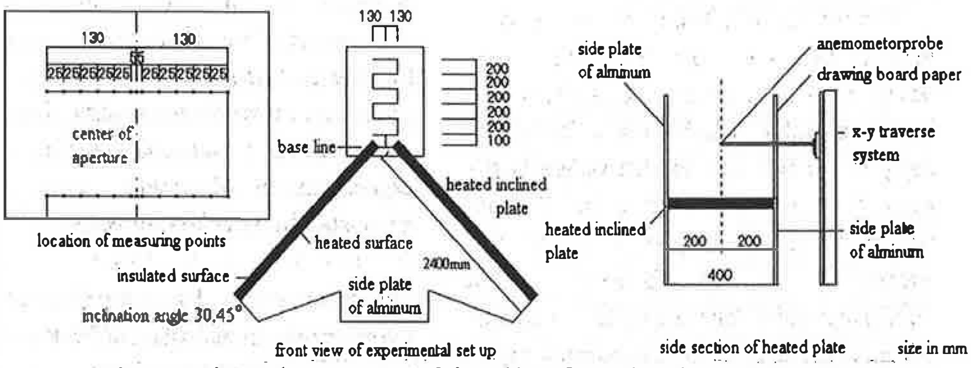

Fig.1 experimental arrangement of air and heat flows along lower surface of roof degrees. The thickness of the velocity boundary and the peak velocity increased with the distance from the lower edge. At a distance of 1800mm, the peak velocity was about 0.5m/s at a interval of about 15mm from the heated surface. The flow rate was calculated to be 13.8l/s/plate width of 1m.

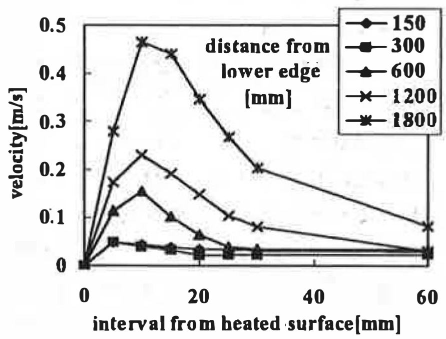

Fig.2 velocity distribution along lower surface of heated plate

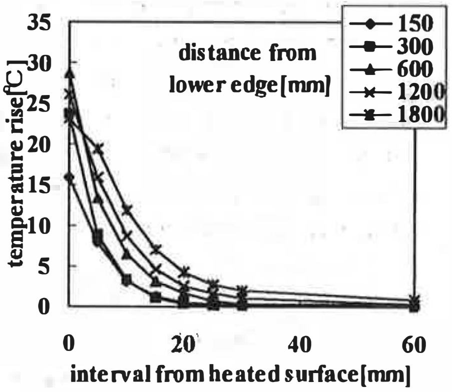

Fig.3 temperature rise distribution along lower surface of heated plate

The velocity distribution curves seems to indicate that the flow is laminar. The equivalent Grashof number was 1.86×10^9 at a height of 1.8m, which was estimated by applying the heat flux and the vertical height from the lower edge. The critical Grashof number for a vertical plate with equivalent temperature is in between 10^8 and 10^9[Holman, 1986]. The present Gr is above the critical value. The natural convection along the lower surface of the inclined heated plate seems to remain in laminar region even the Gr number exceeds the critical value, because the temperature stratification is stable.

The excess temperature distribution in the convection for the same condition as above is shown in figure 3. The surface temperature rose as the height increased, and the excess temperature almost reached to about 30 degrees C at a distance of 1800mm.

Results of experiment 2

Velocity distributions in the plume above the top aperture, which were attained through experiment with an incline angle of 45degrees and an equivalent heat production on the left and right plates of 150W/m^2, are shown in figures 4 a-d. At a level of 100mm above the base level, the peak velocities were 0.61, 0.80, 0.71 and 0.59m/s for the apertures of 10, 20, 50 and 100mm, respectively. The temperature distributions in this condition is shown in figure 5 a-d.

The velocity distribution in an experiment with an incline angle of 30 degrees, an aperture of 50mm and heat productions of 150-150W/m^2 is shown in figure 6. The position of the peak velocity deviated from the center of the aperture. When three measurements were repeated with the same condition, the peak deviation to the right was found in two of the measurements, and the left deviation was found in one of the three measurements. In the observation of the temperature distribution with an infrared camera, irregular wondering of the plume center was observed in this incline angle. This wondering was not observed in the experiments of 45 degrees. In the flow observation by a smoke wire technique, the two upward flow along the left and the right plates collided and stagnated at the top of the space in the experiment of inclination of 30 degrees, but they did not collided, and passed the aperture

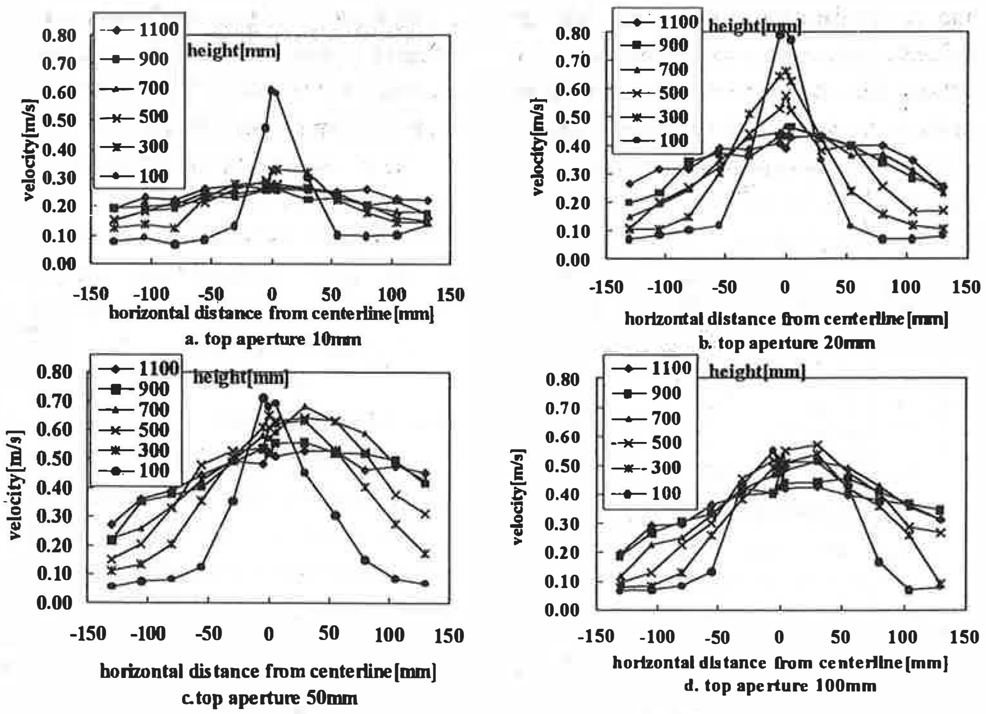

Fig.4 velocity distribution above top aperture

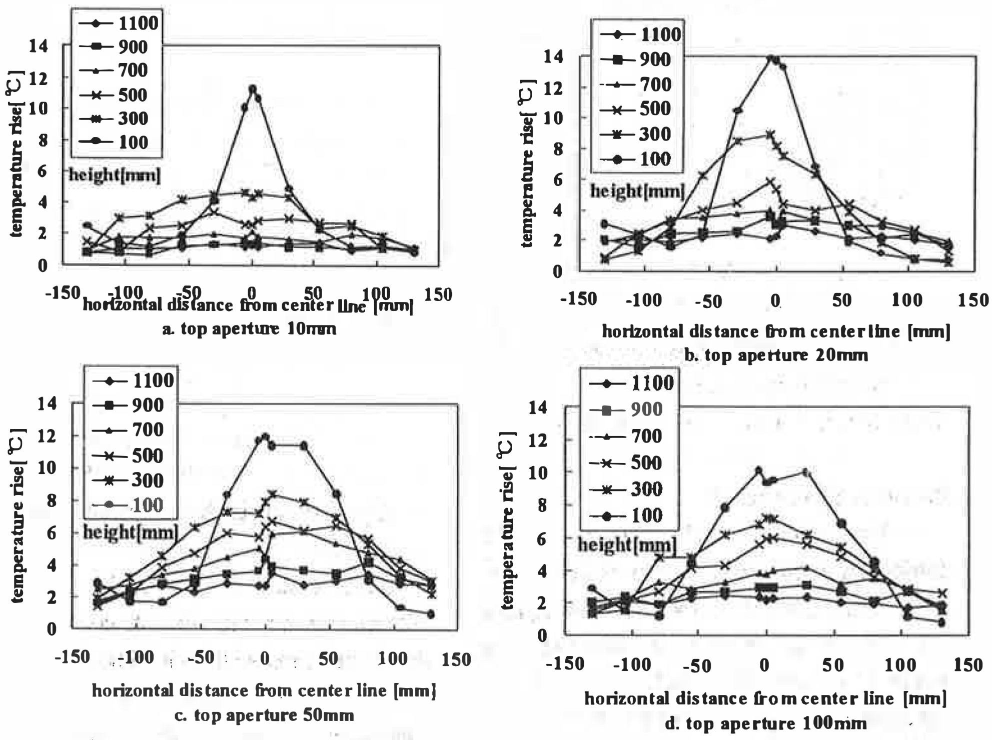

Fig.5 temperature distribution above top aperture smoothly in the case of 45 degrees. But this difference in the flow pattern did not show definite difference in the velocity or temperature distributions between the two incline angles.

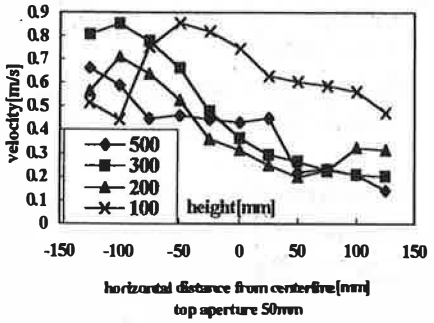

Fig.6 velocity distribution in an experiment with an incline angle of 30 degrees

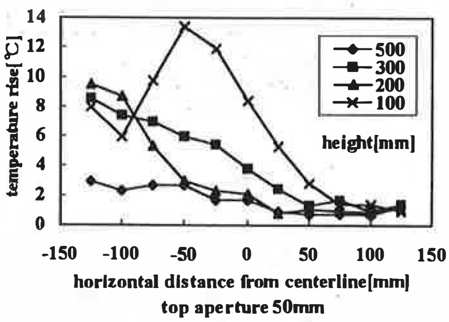

Fig.7 velocity distribution in an experiment with an incline angle of 30 degrees

The temperature distributions of the same experiment is shown in figure 7. The both temperature distribution curves of incline angles of 30 and 45 degrees diffused wider with the height than the velocity distribution curves.

Results of experiment 3

The velocity and temperature rise distributions in the experiment of an aperture of 50mm and a heat flux of the two plates equally 150W/m^2 with a chimneys are shown in figures 8 and 9, respectively. At a level of 100 mm above from the upper end of the chimney, the peak velocity was the highest with the chimney of a height of 500mm. It decreased slightly with the chimney of a height of 100mm, but the influencing area of the flow increased. It decreased significantly with the chimney of a height of 800mm. The temperature in the plume was the highest with the shortest chimney, and the lowest with the longest chimney.

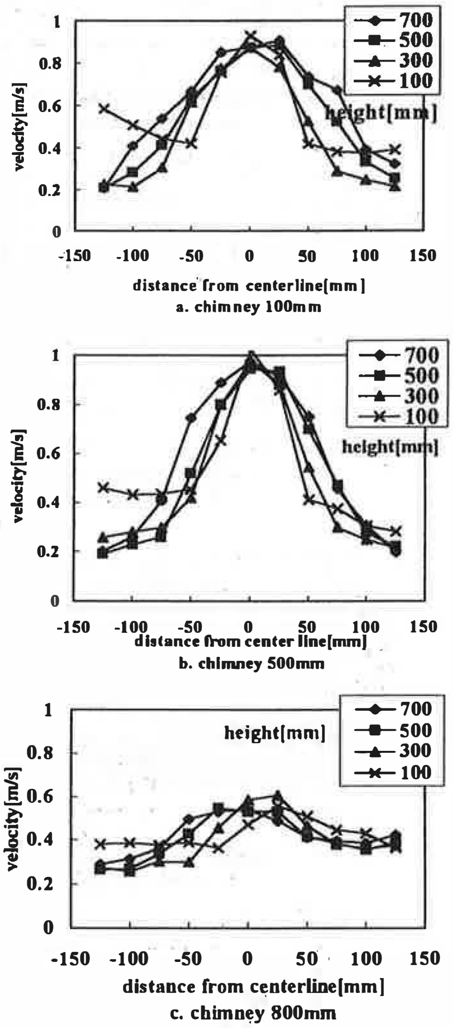

Fig.8 velocity distribution above chimney

When a chimney of a height of less than 500mm was attached, the volume flow rate of the plume increased from it without a chimney. But when a chimney of a height of 800mm was applied, the flow rate decreased from the same conditions but the chimney.

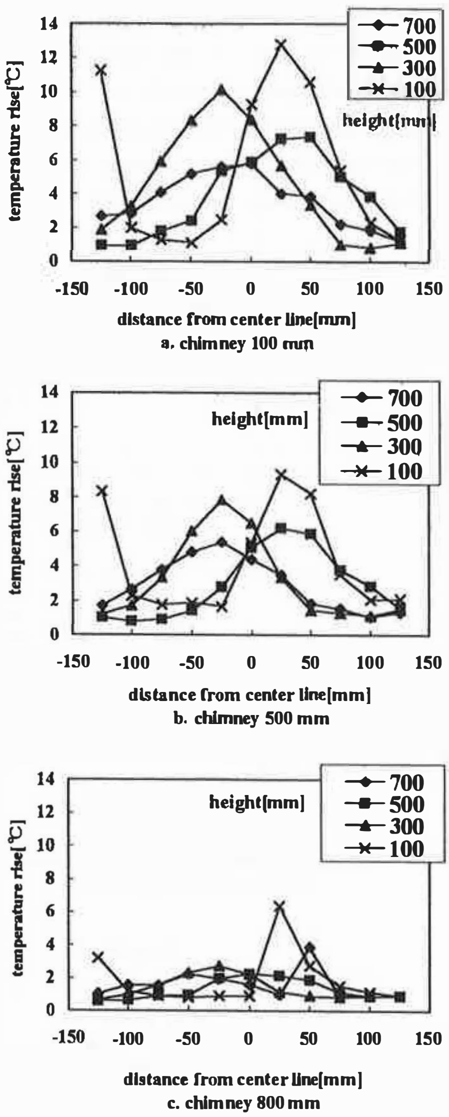

Fig.9 temperature distribution above chimney

CONCLUSIONS

The width of the aperture at the top of an attic has strong influence on the evacuation of hot air, which absorbs solar heat from the lower surface of a roof. In this experimental arrangement, the required aperture to evacuate the hot air effectively seemed to be 50mm or above this, when the aperture was plain. When a chimney was attached to the aperture, the cooling effect was influenced by the height of the chimney. When the aperture was small, the addition of the chimney affected to increase the resistance of the flow, irrespectively with chimney height. When the aperture increased to a width of 50mm, the cooling effect was highest with a chimney of a height of 500mm. The application of a chimney of a height of 800 decreased the cooling effect significantly.

REFERENCES

Holman J.P. (1986) Heat Transfer, Mc Graw-Hill, New York

Murakami T., Homma H., Yamamoto K., Kano M. (1996.9) An experimental study of air and heat flow in apex opening of roof using heat flux inclined surfaces, summaries of technical papers of annual meeting D-2 architectural institute of Japan,95-96(in Japanese)

Yamamoto K., Homma H., Matsumoto H., Shimizu M., Murakami T. (1996.12) Release solar irradiation by natural ventilation of an attic, Journal of Architecture, Planning and Environmental Engineering, architectural institute of Japan,486,11-17(in Japanese)

Yamamoto K., Homma H., Matsumoto H. (1997.11) A Fundamental Study of Solar Heat Removal of Attic by Natural Ventilation, Japan/Canada Housing R&D workshop Proceedings,4,V3-V21