Passive Cooling with Ceiling Insulation

By: K. S. Ong, Tan, B. T., Raymond Joe and K. S. Tan

INTRODUCTION

Tropical countries located near the equator experience hot and humid weather conditions. High ambient temperatures and humidity lead to uncomfortable conditions that are non-conducive for human comfort and productivity. In these countries, mechanical cooling devices like air conditioners and electric fans are often installed. Apart from contributing to the global greenhouse warming effect and depletion of fossil fuel, they are expensive and beyond the reach of the poor. The majority of lower income group in rural areas often live in houses with metal roofing sheets and could ill-afford air conditioners.

The conventional pitch roof design of a typical Malaysian house involves the use of concrete roof tiles or corrugated metal roofing sheets together with a sheet of cement board between the roof and the living space. During the day, heat is absorbed by the roof and trapped in the attic space between the roof and the ceiling. The thermal performance of such houses could be improved by orientating the building to allow prevailing winds to blow across the house and by providing more openings in the building design. Solar passive devices such as the Trombe wall, roof solar collector and ceiling insulation shown in Figure 1 could be incorporated into the building design to assist in providing a comfortable and cool environment within the house. The Trombe wall concept, Figure 1(a), incorporates an external transparent cladding next to the conventional vertical outside wall. Solar energy passes through the cladding and is absorbed by the inner wall. Air immediately adjacent to the inner wall is heated and rises up the cavity created between the two walls. Vents walls allow air to be drawn in at the bottom and exhausted out from the top. The amount of heat conducted into the attic could be reduced by placing a solar air heater over the existing roof or the conventional roof design could be modified to incorporate some form of air passage underneath the roof, as shown by the roof solar collector concept in Figure 1(b). Since hot air rises due to buoyancy effects, the induced air stream would cool the underneath of the roof. Properly designed and constructed, this induced air stream could be ducted in such a way as to aid in the ventilation of the attic or the living space in the interior of the house, thus keeping the house cool. Provision of a ceiling insulation, Figure 1(c), could help reduce the ceiling temperature but would not cause nor increase fresh air intake into the building.

The criteria for "thermal comfort" differs for different countries and ethnic groups. For example, ASHRAE Standard 55a-1995 [1] gives the upper limits of 26°C and 20°C, for dry and wet bulb temperatures, respectively, for human comfort. An important parameter in the determination of human comfort is the velocity of air flowing past the human body. Tantasavasdi *et. al.* [2] stated that the upper limit of temperatures at wind speeds of 0.2, 0.4 and 1 m/s were 29.1, 29.9 and 31.3°C dry bulb and 23.0, 23.5 and 24.5°C wet bulb, respectively. Khedari *et. al.* [3] found similar trends for Thailand's hot and humid weather conditions. Wong et. al. [4] reported that occupants of public housing in Singapore were generally satisfied with natural ventilation as the majority of the people were perhaps already acclimatised to the local hot and humid climatic conditions. Studies conducted by Karyono [5] and Feriardi and Wong [6] in Indonesia showed similar conclusions, that occupants were prepared to accept a higher thermal comfort level. Ong and Chow [7] showed that the Trombe wall was able to induce sufficient fresh air circulation within the building as required by the local Building codes. In a further work, Ong *et. al.* [8] showed that although the roof solar collector had the effect of providing a cooler attic and room interior, the induced ventilation rate although sufficient for fresh air ventilation was inadequate to provide for human comfort within the room.

Mathews *et. al.* [9] determined the economic viability of providing ceiling insulation in middle-income houses in South Africa. Their study showed that annual savings per household alone did not seem to justify the cost of ceiling insulation as expected pay-back periods were too long. Monetary savings on their own could not be used to motivate the public to install ceiling insulation. Since savings were too low to convince home owners to insulate their ceilings, Taylor *et. al.* [10] investigated other benefits such as improving indoor thermal comfort with insulated ceilings. They showed that average temperature improvement of about 3°C could be obtained inside a house after insulation was installed.

The objective of the present investigation would be to determine the cooling effect in the interior of a metal roof shed by providing ceiling insulation and to compare its thermal performance with that of another without insulation.

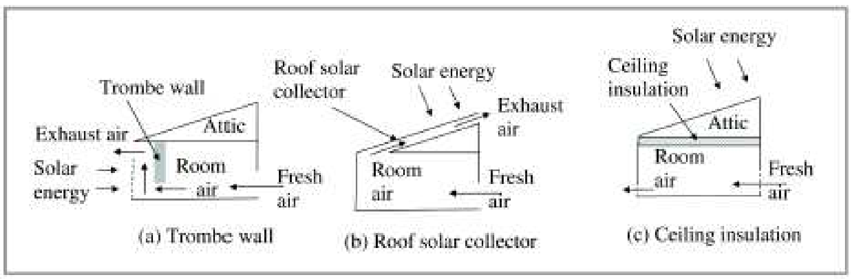

Figure 1: Solar passive devices

Figure 2: View of the experimental sheds

EXPERIMENTAL SHEDS

Two lab-size sheds were constructed, each measuring 1.8 m long x 1.2 m wide as shown in Figure 2. The 25° pitch roofs of both sheds were fabricated from 2 m long by 0.4 mm thick GI sheets. The height of the roof was 1.0 m from the ground at the lower end. The walls were of 10 mm thick cement boards and the floor, 12 mm thick plywood. Although openings were provided at the rear of the sheds for access to the interior, they were kept shut during the experiment. Hence the experiments were performed without any internal ventilation. One of the shed was used as a control shed for performance comparison. The other, referred to as the "insulated" shed here, was provided with a 50 mm thick rockwool blanket insulation on top of the ceiling board. Both roofs were painted black. Copper constantan thermocouples monitored the temperatures at various locations on the surface of the roof and top of the ceiling board, inside the attic and interior of both sheds and the ambient. A solarimeter measured the solar radiation intensity falling on an inclined plane parallel to the roof. Tests were conducted from 9 a.m. to 5 p.m. All measurements were logged every 5 minutes with a data logger.

EXPERIMENTAL RESULTS

Typical results for daily ambient temperature, solar radiation intensity, temperatures at the center of the roof and top of the ceiling board, in the attic and interior of the sheds are shown in Figures 3 and 4. The radiation intensity and the ambient temperature patterns are quite representative of the fluctuating ambient conditions experienced throughout the day in the tropics. As a result, all the measured temperatures fluctuated, rising and falling with the solar radiation intensity.

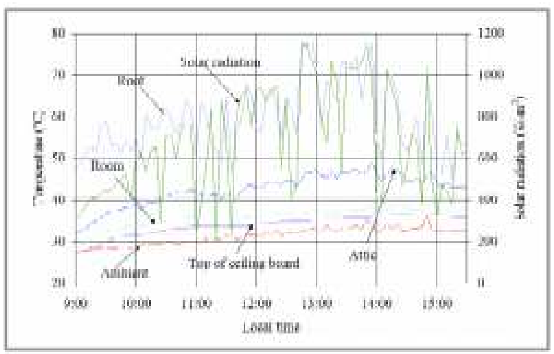

Figure 3: Daily temperatures for insulated shed

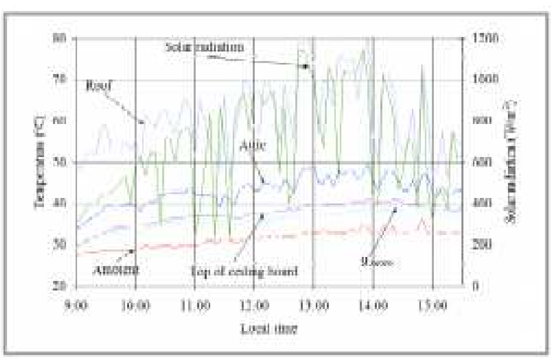

Figure 4: Daily temperatures for control shed

The following typical results were observed:

1. Solar radiation intensity peaked at around 1 p.m.
2. Ambient temperature rose steadily and peaked at around 3 p.m.
3. All other temperatures fluctuated in tandem as the day progressed.
4. The roof recorded the highest temperature, as expected, reaching beyond 70°C around 12.30 p.m followed by the attic at around 48°C.
5. The room temperatures were always higher than ambient peaking around 38°C at about 2 p.m.
6. In the insulated shed (Figure 3) the top of the ceiling board was about 10°C lower than the attic and about 2°C lower than the room underneath.
7. In the control shed (Figure 4), the top of the ceiling board was about 10°C lower than the attic but about 2°C higher than the room underneath.
8. The last two observations indicate that the insulation prevented any heat transfer between the attic and the room underneath.

Figure 5 shows a typical comparison of the daily temperatures of the roofs. It could be seen that the roof temperatures were nearly equal. Figure 6 compares the daily temperatures in the room, attic and top of ceiling board in the sheds. Within the experimental accuracy of + 1°C, the room and attic temperatures could be said to be very nearly equal. However, the ceiling board of the insulated shed was as much as 5°C lower than that in the control shed. In the insulated shed the top of the ceiling was about 5°C lower than the room temperature while in the control shed it was about 5°C higher. With a lower ceiling board temperature, the amount of radiant heat from the ceiling to the occupants underneath would be reduced. This showed that although the room temperature was not appreciably affected, the ceiling insulation was able to improve thermal comfort by lowering the ceiling temperature and hence reducing radiant heat from the ceiling.

Although both the experimental sheds were un-ventilated leading to heat build-up inside which may not represent actual operating conditions of an actual house, the comparative results could lead to a better understanding of the heat transfer involved which would lead to a better theoretical model.

CONCLUSIONS

The study shows that ceiling insulation would lead to reduced ceiling temperature but would not reduce the room temperature. A lower ceiling temperature would lead to reduced thermal radiation load on the occupants in the room.

ACKNOWLEDGEMENT

Thanks are extended to CSR Building Materials S/B for providing the experimental sheds.

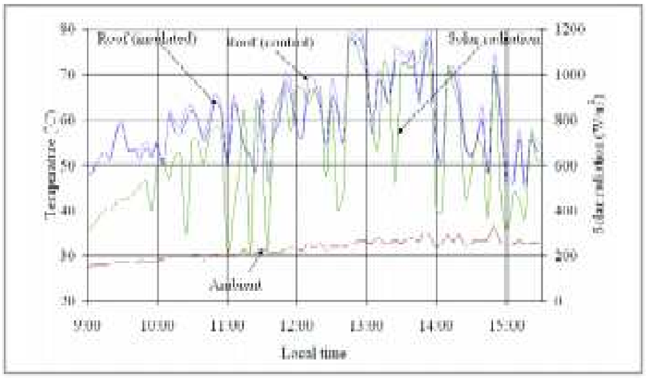

Figure 5: Comparison of roof temperatures

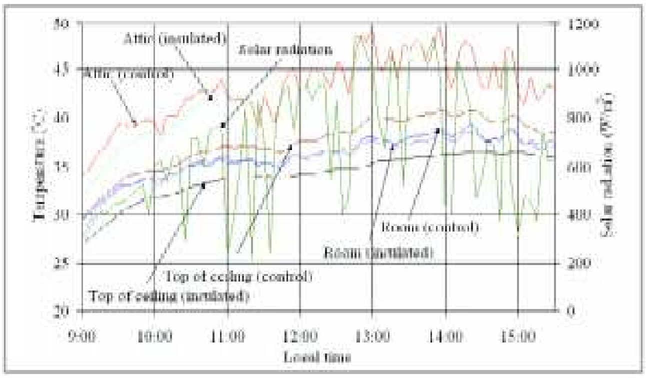

Figure 6: Comparison of attic, room and top of ceiling

REFERENCES

[1] ASHRAE, Thermal environmental conditions for human occupancy. ASHRAE Std. 55a-1995, ASHRAE, 1995.

[2] Tantasavasdi, C., Srebric, J. and Chen, Q., Natural ventilation design for houses in Thailand. Energy & Buildings, 33, 815-824, 2001.

[3] Khedari, J., Yamtraipat, N., Pratintong, N. and Hirunlabh, J., Thailand ventilation comfort chart. Energy and Buildings, 32, 245-249, 2000.

[4] Wong, N. H., Feriadi, H., Lim, P. Y., Tham, K. W., Sekhar, C. and Cheong, K. W., Thermal comfort evaluation of naturally ventilated public housing in Singapore. Building and Environment, 37, 1267-1277, 2002.

[5] Karyonon, T. H., Report on thermal comfort and building energy studies in Jakarta – Indonesia. Building and environment, 35, 77-90, 2000.

[6] Feriadi, H. and Wong, N. H., Thermal comfort for naturally ventilated houses in Indonesia, Energy and Buildings, 36, 614-626, 2004.

[7] Ong, K. S. and Chow, C. C., Performance of a solar chimney. Solar Energy, 74, 1-17, 2003.

[8] Ong, K. S., Tan, B. T., Raymond Joe and Tan, K. S., Solar passive cooling with solar collector roof. (To be presented at APCSEET, Thailand, 2007).

[9] Mathews, E. H., Kleingeld, M. and Taylor, P. B., Estimating the electricity savings effect of ceiling insulation. Building and Environment, 34, 505-514, 1999.

[10] Taylor, P. B., Mathews, E. H., Kleingeld, M. and Taljaard, G. W., The effect of ceiling insulation on indoor comfort. Building and Environment, 35, 339-346, 2000.