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Field measurements of performance of roof solar collector

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Abstract

To reduce the mechanical cooling energy cost of new housing built in a hot and humid region, the design should maximize the natural ventilation and minimize the fraction of sun energy absorbed by a dwelling. This objective is accomplished by using the roof structure to act as a solar collector. The roof solar collector design (RSC) used CPAC Monier concrete tiles and gypsum board. Two units of RSC were integrated in the roof structure of the school solar house. The effects of air gap and openings of RSC on the induced air flow rate and thermal comfort were studied experimentally. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Roof solar collector; Natural ventilation; Air gap; Openings

1. Introduction

Nowadays, houses in Bangkok have various modern styles with much more emphasis on the beauty of the outside than on the resident's thermal comfort. In addition, most of the residents ignore the follow effect. One of the problems is that the resident does not have enough knowledge about each characteristic of design of the residence. For example, residences located in Europe are designed for storage heat and the ceiling design under the roof is a close system for preventing heat from spreading out. In addition, the roof is made of dark color bricks (red, blue and orange), so it can absorb the solar radiation well. Opposite design has to be made for residences situated in hot and humid areas. However, as mentioned above, Thai architects often make use of western models to design houses. This leads to overheating the air under the roof structure as no air vents are provided. Therefore, heat will be transmitted to the interior of the residence through the ceiling during daytime [1,2] which in turn will force the residents to use air-conditioners with a high cooling load. To overcome this, we propose to use the roof structure to act as a solar collector to reduce heat transmitted into housing (reducing cooling load) by inducing natural air circulation [3–6] which is a part of the house's thermal comfort.

The roof solar collector (RSC) comprises, mainly of two parts: CPAC Monier roof tiles on the outer part and gypsum at the inner part (house side), Fig. 1. Initial investigation of performance of such unit was reported in former publication [3]. It concerned a separate unit of RSC and tests were carried out on different days which limited the comparison between different results. Nothing about effectiveness of RSC to induce natural ventilation was mentioned. In this paper, two units of RSC, tilted at 25°, were integrated into the south-facing roof of the single-room solar house model [7,8]. Their design allows us to test different air gap (8 and 14 cm) and different free opening vents. The house was built at the 12th floor of the school, Fig. 1. Its dimensions are as follows: 2.68 m height, 3.35 m width and 3.45 m length. The solar house has a window and a door with a grill on the northern side. The inner side of lateral walls was made of plywood while the outer side was made of gypsum flash sheet. The roof was made by using CPAC Monier concrete tile dark red color. The floor was plywood on grade.

2. Configurations studied and experimental method

The surface area of the RSC unit is considered equal to 1.5 m^2 ($L \times W$: 1.5×1 m^2). The outer side was made by

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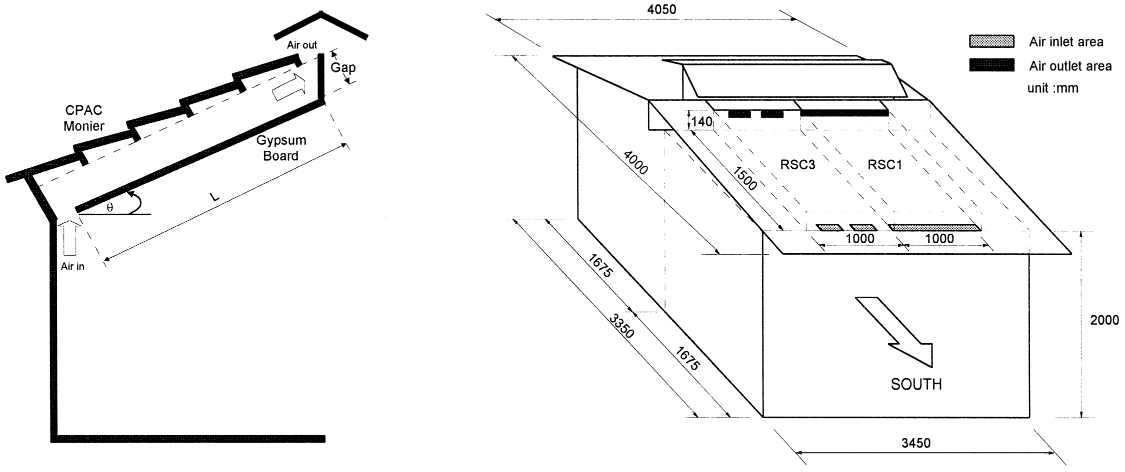

Fig. 1. Schematic representation of RSC integrated in the roof structure.

CPAC Monier concrete tiles ($33 \times 42 \times 1.5$ cm^3; 4.4 kg/piece); dark red color while the inner one was made of gypsum board ($100 \times 150 \times 0.9$ cm^3; 1.7 kg). Four configurations were considered as shown in Fig. 2.

Thermocouples of type K were used to measure the temperature of air, CPAC Monier tiles and gypsum board at different points on the RSC units (Fig. 3) and in the room (Fig. 4). Thermal probes were used to measure the air velocity at several points of RSC units (Fig. 5); then, an average value was calculated.

Experimentation started at 8:00 a.m. and ended at 5:00 p.m. by recording data of the two units of RSC simultaneously at 30 min intervals.

3. Results

3.1. RSC temperatures

An example of variation of ambient conditions is given in Fig. 6.

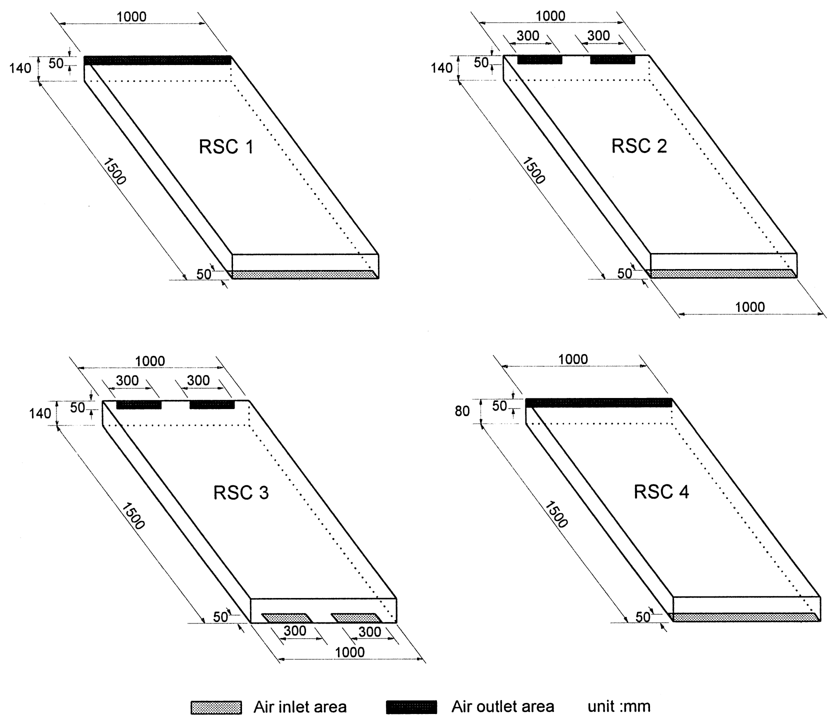

Fig. 2. Dimension of the four types of the RSC for experiment.

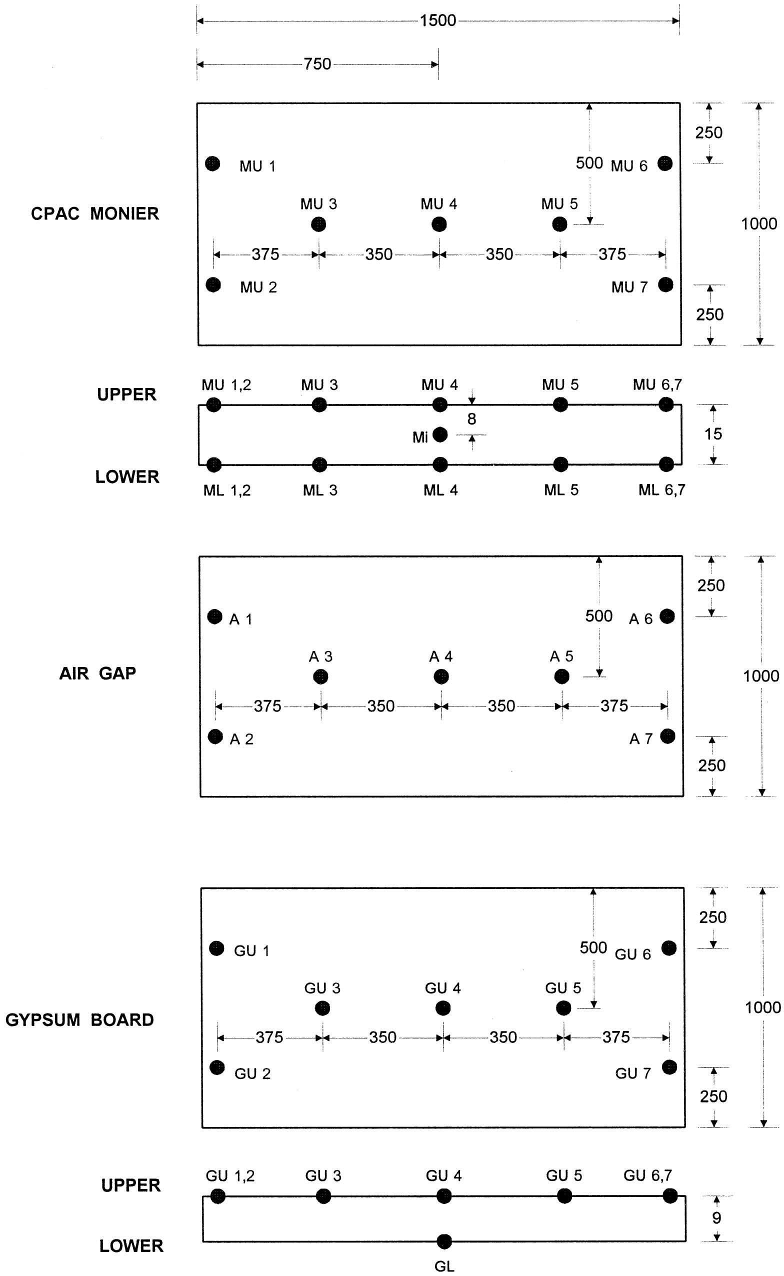

Fig. 3. Positions of thermocouples setting through RSC.

Fig. 7 shows that the temperature of CPAC Monier, air and gypsum board is changing along with the intensity of solar radiation. At entry of RSC, Fig. 8, the temperatures were lower because of incoming room air into the RSC while at outlet of RSC, the mixture between outgoing air with ambient and partial shading caused by the 'hat' of outlet opening led to decreased temperature. In addition, no significant difference between temperatures of the two configurations RSC1 and RSC2 was observed. Therefore, analysis of performance of different configurations has to be made based mainly on induced air flowrate.

From Fig. 9, it can be seen that the temperatures of air gap at two different positions at equal distance from the inlet, (A6 and A7, see Fig. 3), were similar, except around 1:30 p.m. Thus, with regard to developing a numerical model assuming a uniform temperature along the width of RSC is acceptable.

3.2. Effect of air gap

Fig. 10 shows the variation of induced air flowrate by RSC with two different air gap spacing. It was found that with 14 cm air gap (RSC1), the air flowrate is higher than

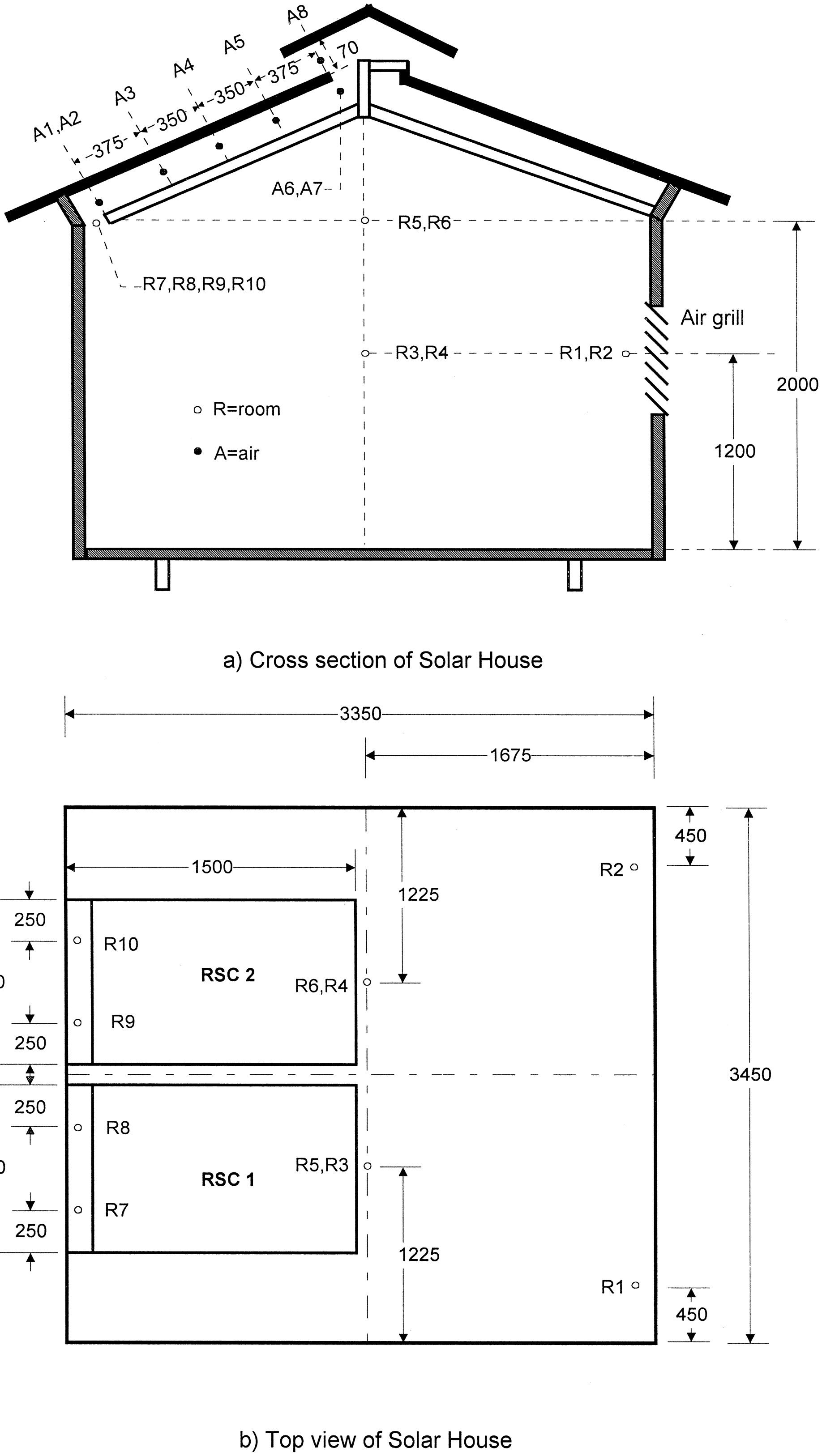

Fig. 4. Positions of room temperature measurement.

that induced with 8 cm air gap (RSC4). Therefore, large air gap is recommended. It should be noted that air flowrate was almost independent of variations of wind velocity that is opposite to what was excepted as actually wind would

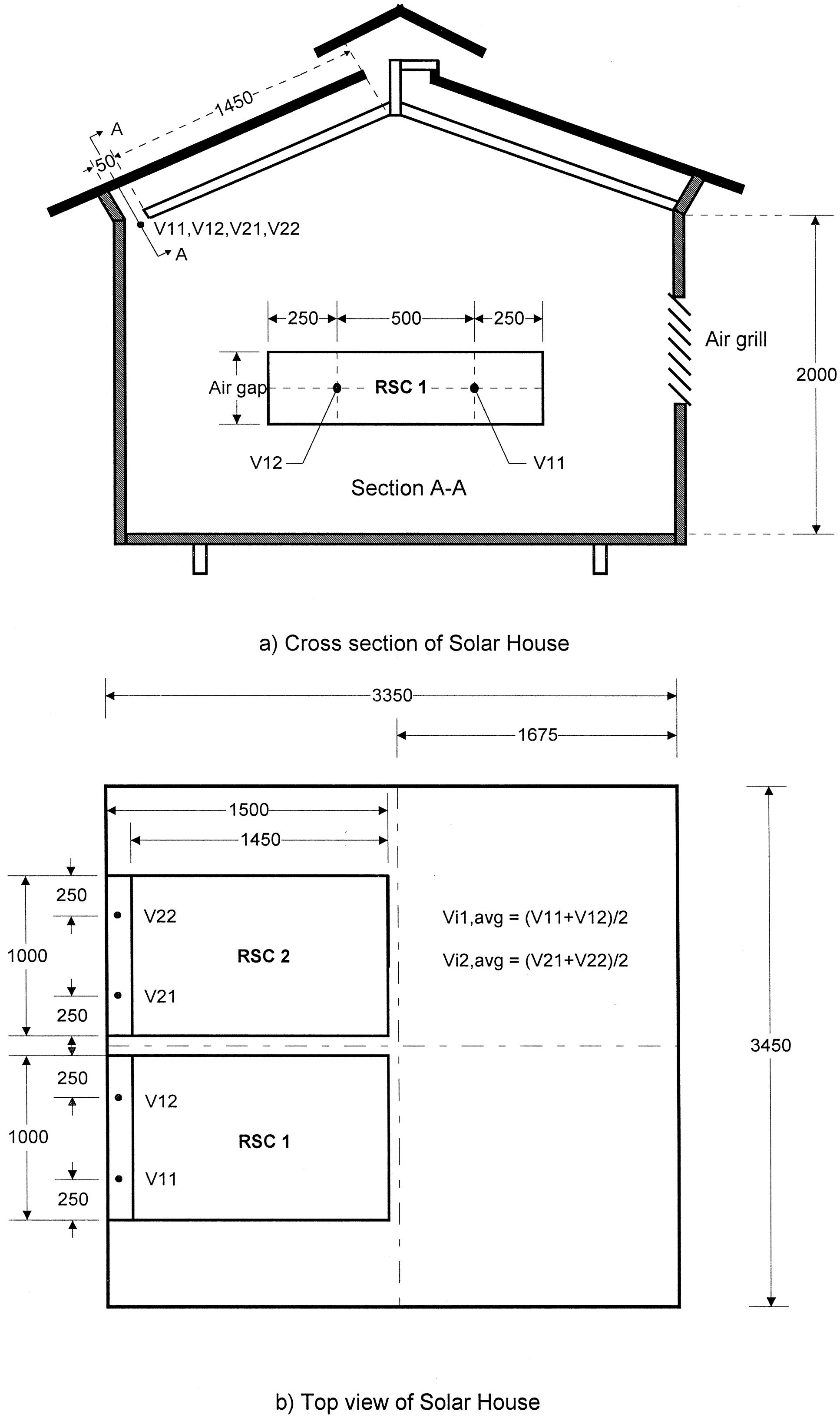

Fig. 5. Positions of air velocity measurement.

increase the induced air flowrate [9–11]. In fact, those papers disregarded the fact that wind will cool the outer surface of the CPAC Monier leading to decreased temperature of the air chimney and, consequently, decreased air

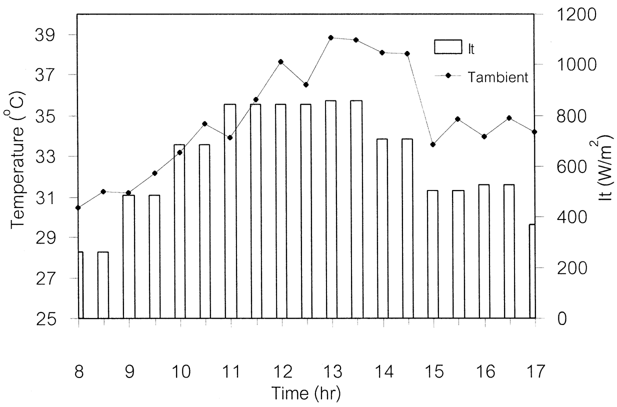

Fig. 6. Hourly variation of ambient air temperature and solar intensity on a horizontal plane (29/8/1998).

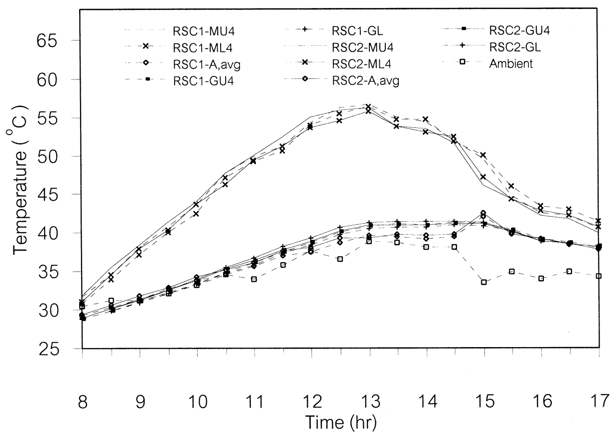

Fig. 7. Hourly variations of the temperature of CPAC Monier tiles, air and gypsum board for the configurations RSC1 and RSC2 (29/8/1998), (Average temperature of air gap; A,avg = (A1 + A2 + … + A7)/7).

flowrate induced by RSC. However, this loss is compensated by the wind induced air flowrate. So, the induced air flowrate by RSC seemed to be wind independent. In revanch, when solar intensity is rather weak or started to decrease as it is the case in the afternoon, wind will help very effectively in inducing air circulation.

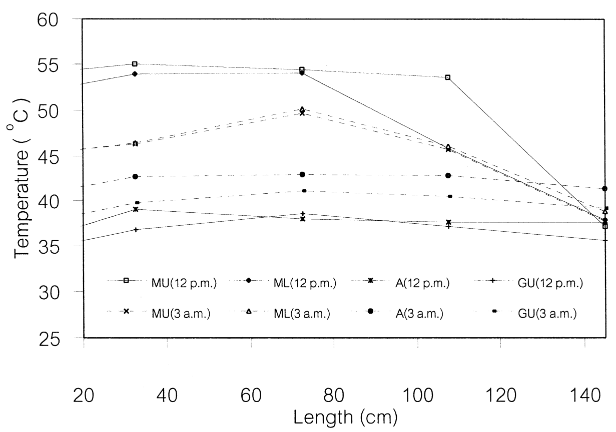

Fig. 8. Longitudinal temperatures of the RSC1 at two times (29/8/1998).

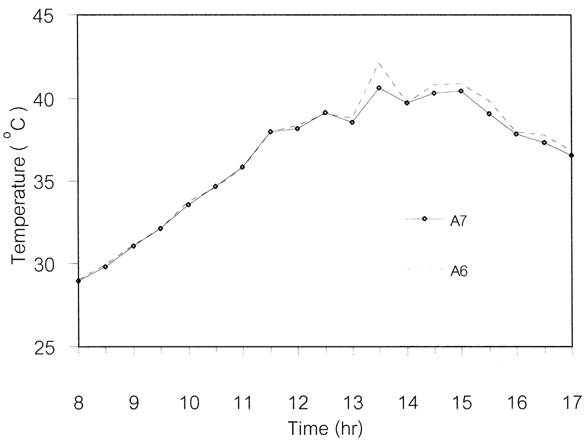

Fig. 9. Variation of air gap temperature at two position at equal distance from the inlet vs. time of the RSC1 (30/8/1998).

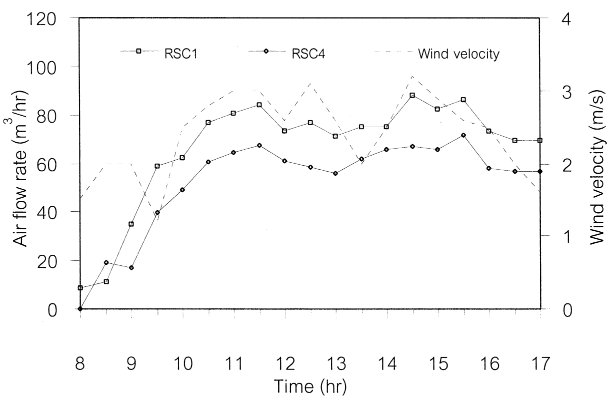

Fig. 10. Variation of induced air flowrate of the configurations RSC1 and RSC4 (13/12/1996).

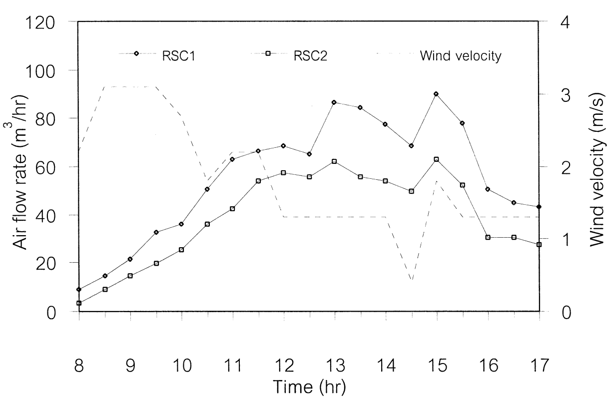

Fig. 11. Variation of induced air flowrate by the configurations RSC1 and RSC2 (29/8/1998).

3.3. Effect of openings of RSC

Figs. 11 and 12 illustrate the variation of induced air flowrate by RSC for the different opening vents (RSC1, RSC2 and RSC3). It was found that with equal and larger size of free inlet–outlet openings, configuration RSC1, the induced air flowrate was the highest one. Therefore, opening vents have to be of equal size and as large as possible.

3.4. Induced air ventilation and thermal comfort

The induced mechanism of ventilation could be viewed based on room temperature of different positions, as shown in Fig. 13. The room temperature near the door and window grills (points R1 and R2, see Fig. 4) was close to ambient, indicating the coming of ambient air into the room. The room temperature 2 m above the floor (R5,R6) was higher than that near the floor (R3,R4), which is obvious, as hot air rises. The temperature of air ingoing into the RSC units (R7,...,R10) was the highest one, which is obvious, due to heat transferred through the southern walls and roof.

In addition, till 2:00 a.m. the average room temperature was very close to ambient air demonstrating the efficiency of RSC for reducing heat accumulation in housing by inducing natural ventilation. In fact, with closed RSC, a temperature difference between room and ambient up to 10–12°C was observed. At 3:00 p.m. the solar intensity as well as temperature of ambient suddenly decreased resulting in a relatively higher difference between ambient and room temperature.

However, with both units of RSC (3 m^2), the average number of induced air change is about 4–5 ACH, which is not sufficient to satisfy complete resident thermal comfort. A higher number of ACH, depending on season, (up to 20) is required for houses without any mechanical cooling device. This could be done by increasing the surface area of RSC, i.e., increasing the number of RSC units and making use of walls to act similarly.

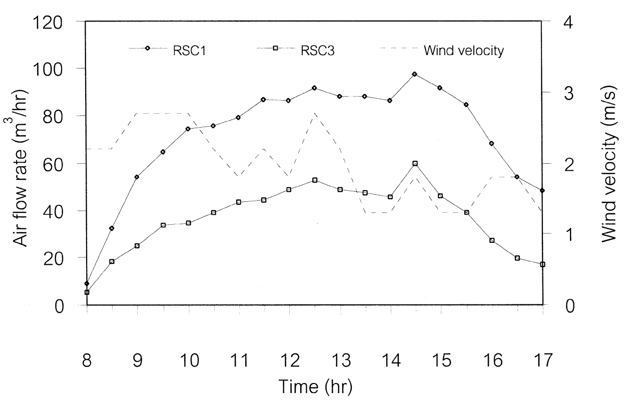

Fig. 12. Variation of induced air flowrate by the configurations RSC1 and RSC3 (30/8/1998).

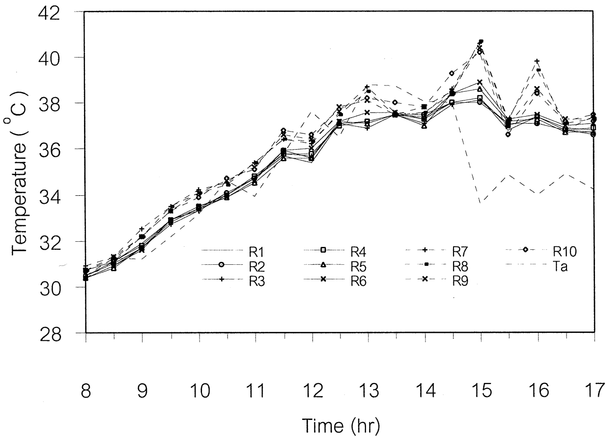

Fig. 13. Variation of air temperature at different position vs. time of the RSC1 (29/8/1998).

4. Conclusion

The use of RSC to reduce the rate of heat transferred through a ceiling by inducing natural ventilation has been studied experimentally. The RSC was made by using CPAC Monier concrete tiles on the outer side and gypsum board on the inner.

The experimental results showed that large air gap and large and equal size of openings would induce the highest rate of air flowrate.

In addition, as extra cost of the construction according to the proposed configuration would not increase very significantly; designer and architects should consider these proposition in their further designs.

Finally, with only a RSC system, there is little potential in inducing sufficient natural ventilation to satisfy residents' comfort. However, if another device such as Trombe wall was used together with Roof Solar Collector in a real building, the cooling 'ventilation' efficiency will be improved. This awaits full-scale testing to demonstrate the comfort of such housing.

Acknowledgements

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