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Ventilation impact of a solar chimney on indoor temperature fluctuation and air change in a school building

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Abstract

The aim of this research was to investigate, experimentally, both the feasibility of a solar chimney to reduce heat gain in a house by inducing natural ventilation and the effect of openings (door, window and inlet of solar chimney) on the ventilation rate. The study was conducted using a single-room school house of approximately 25 m^3 volume. The southern wall was composed of three different solar chimney configurations of 2 m^2 each, whereas, the roof southern side included two similar units of 1.5 m^2 each of another solar chimney configuration. Those configurations were built by using common construction materials. Experimental observations indicated that when the solar chimney ventilation system was in use, room temperature was near that of the ambient air, indicating a good ability of the solar chimney to reduce house's heat gain and ensuring thermal comfort. The air change rate varied between 8–15. Opening the window and door is less efficient than using solar chimneys, as temperature difference between room and ambient was higher than that obtained with solar chimneys.

Keywords: Natural ventilation; School building; Tropical region; Field testing; Thermal comfort

1. Introduction

Natural ventilation may result from air penetration through a variety of unintentional openings in the building envelope, but it also occurs as a result of manual control of building's openings (doors, windows) or — when a building is equipped with a ventilation system — like natural ventilation solar chimneys. Air is driven in/out of the building as a result of pressure differences across the openings, which are due to the combined action of wind and buoyancy-driven forces.

Today, natural ventilation is not only regarded as a simple measure to provide fresh air for the occupants, necessary to maintain acceptable air-quality levels, but also as an excellent energy-saving way to reduce the internal cooling load of housing located in the tropics. Depending on ambient conditions, natural ventilation may lead to indoor thermal comfort without mechanical cooling being required.

Many configurations of solar chimneys have been used widely in the past and many are being developed again today [1–4]. In our school, several studies were carried out in this topic since 6 years [5–8]. Four configurations of solar chimney, each with approximately 2 m^2 of surface area, were built by using common construction materials: The Roof Solar Collector (RSC) [5], the Modified Trombe (MTW) [6], the Trombe Wall (TW) [7] and the Metallic Solar Wall (MSW) [8]. The description and dimensions of each configuration are given in Fig. 1 and Table 1.

These configurations were integrated into the south-facing roof and facade of a single-room building of approximately 25 m^3 volume. The room was located at the 12th floor of the School of Energy and Materials. Tests were run separately.

It was found that all of these devices allow, on the one hand, to minimize the fraction of the solar flux absorbed by the dwelling acting, therefore, as a very good insulation material and, on the other hand, to induce a natural ventilation which improves thermal comfort. However, the resulting number of air changes (ACH) was rather low varying — depending on climate conditions — between 3

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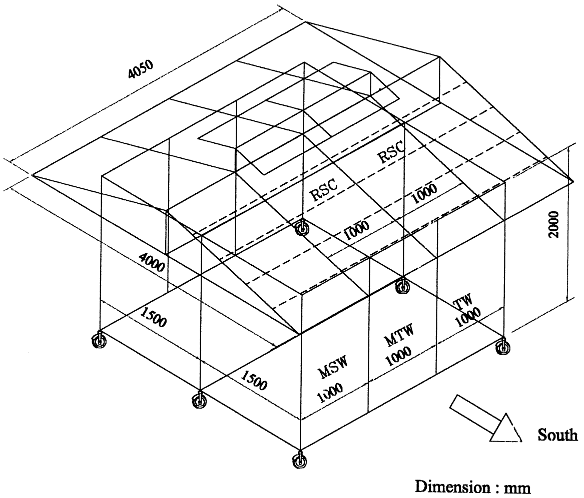


Fig. 1. Dimensions of the single-room solar house.

to 5, which is not sufficient to completely satisfy room occupants as a higher number is required (above 20 ACH) for houses without any mechanical cooling device. So, to increase the ACH, all devices have to act simultaneously. This is the objective of this work: running the four configurations and discussing the resulting thermal comfort by means of three parameters: indoor air temperature and velocity and the number of ACH. However, as tests would have to be done on different days, a relativeness index was introduced. This index is the temperature difference between average room temperature and ambient. In addition, the effect of openings — door, window, and position of free inlet of wall solar chimneys — was also investigated.

2. Methodology

Thermocouples of type K were used to measure the temperature of incoming ambient air through door/window (Fig. 2), air at both inlet and outlet of four configurations of solar chimney (Figs. 3–5). Room temperature was measured at 27 (3×9) positions, between 50 cm above floor to 2 m as shown in Fig. 6. Air velocities at the same position were measured by hot wire anemometers.

The door of approximately 2 m^2 surface area has two air grills located at the upper and lower parts of the door. Investigations were made for the several positions (upper opened/lower closed, upper closed/lower opened and both opened).

The ambient temperature, wind velocity and wind direction were measured by an environmonitor (model of RJ1412HPL; Type: 4X) located about 20 m from the house. The solar radiation was measured by an Eppley precision spectral pyranometer and pyranometer with shading ring [9].

Experimentation started at 9 AM and ended at 5 PM by recording data at 30-min intervals.

3. Results

We remind that the ability of the solar chimney to offer thermal comfort is expressed by the difference (dT) between indoor and ambient temperature. The lower dT is, the higher the rate of ventilation, meaning higher ACH.

The relativeness index was introduced in order to have a tool for comparison of performance as testing this naturally ventilated room was undertaken on different days corresponding to different ambient conditions as shown Fig. 7. This, of course, cannot overcome this problem but it will allow us to formulate general and subjective conclusions.

As mentioned in Section 1, the focus of this paper is on to see how effective such devices would be in aiding ventilation and reducing interior air temperature.

Table 1
Configurations of solar chimney

Configuration (dimension, cm)	Detail of materials (from outside to inside of the house)	Dimension (cm)
TW	Glass	W:L:T:100:200:0.5
(W:L:T:100:200:25.9)	Air gap	W:L:T:100:200:14.5
	Masonry	W:L:T:100:200:8
	Fibre glass	W:L:T:100:200:2.5
	Plywood	W:L:T:100:200:0.4
MTW	Masonry	W:L:T:100:200:8
(W:L:T:100:200:22.9)	Air gap	W:L:T:100:200:14
	Gysum board	W:L:T:100:200:0.9
MSW	Glass	W:L:T:100:200:0.5
(W:L:T:100:200:17.97)	Air gap	W:L:T:100:200:14.5
	Zinc sheet	W:L:T:100:200:0.07
	Fibre glass	W:L:T:100:200:2.5
	Plywood	W:L:T:100:200:0.4
RSC	CPAC monier	(W:L:T)/piece:33:42:1.5
(W:L:T:200:150:16.4)	Air gap	W:L:T:200:150:14
	Gypsum board	W:L:T:200:150:14

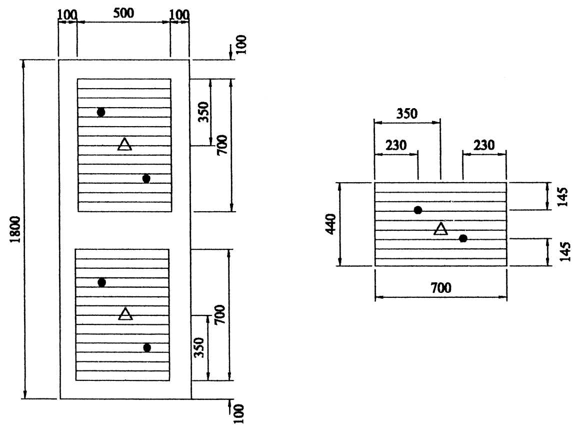


Fig. 2. Measured positions at the door and window. (△) Air temperature; (●) air velocity.

3.1. Indoor temperature fluctuation

Fig. 8 shows that when all openings were closed (door and window grills and free inlet of solar chimney), the temperature difference between room (average of 27 points, see Fig. 6) and ambient increased rapidly with time to reach a maximum of 6°C around 5 PM. The corresponding indoor temperature is, therefore, too high at about 40°C. It should be pointed out that after sunset (around 6 PM) this temperature difference is still important; because of the heat stored during daytime, leading to uncomfortable feeling of warmth at the beginning of the evening. This will force the occupants to turn on the air conditioning, with a very high cooling load.

When the room's common openings (door and window) were open — which is commonly known as ''one side ventilation'' — this temperature difference decreased but is still relatively important, around 4°C.

When the solar chimney opening was opened (wall chimneys opened at 1 m above floor, Fig. 5), corresponding to a total of 6 m^2 of solar chimney surface area (3 m^2 of RSC and 1 m^2 of each wall configuration), this temperature difference decreased. The maximum difference was about 3°C which occurred around 4 PM. The same observation was obtained when the wall chimneys were opened at 0.04 m above floor (Fig. 4), corresponding to a total of 9 m^2 of solar chimney surface area (3 m^2 of RSC and 2 m^2 of each wall configuration). In other terms — even though tests were undertaken on different days — the ventilation induced by solar chimneys reduced room overheating (relativeness index) by about 50%.

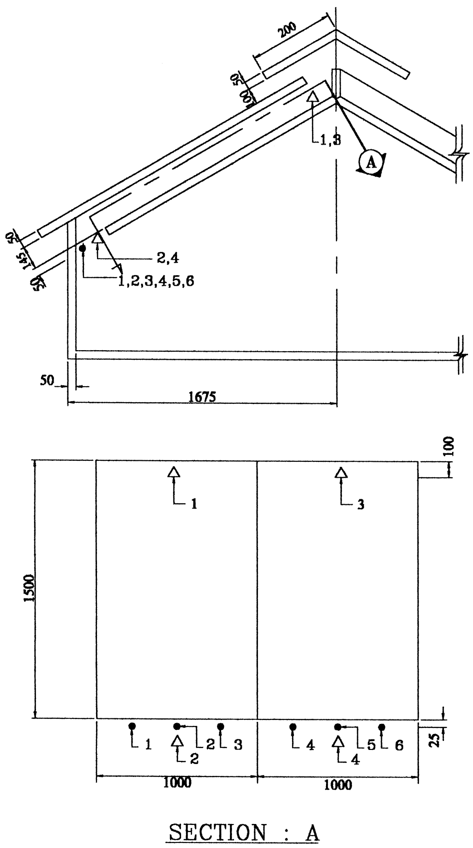


Fig. 3. Measured positions on the RSC. (△) Air temperature; (●) air velocity.

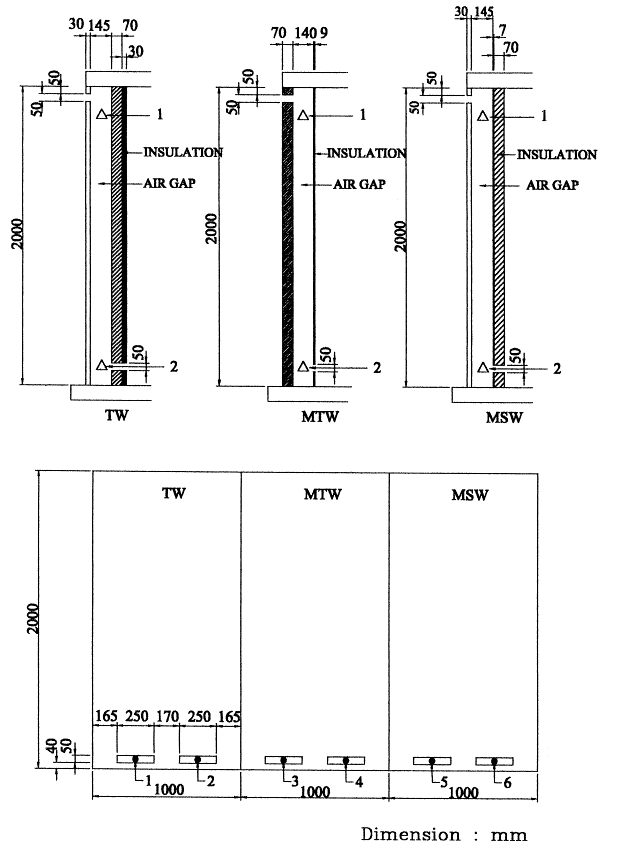
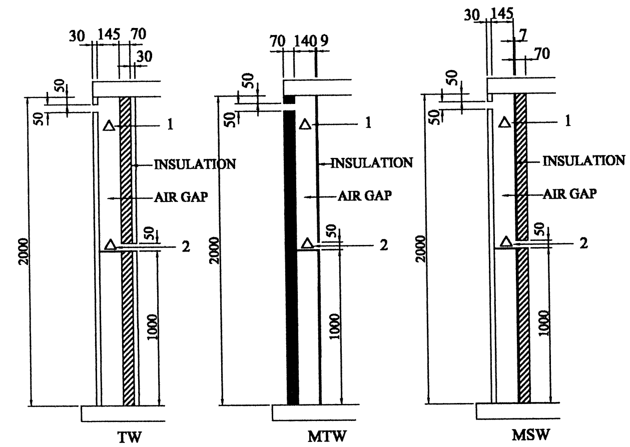


Fig. 4. Measured positions on each type of walls with inlet openings at 0.04 m above floor. (△) Air temperature; (●) air velocity.



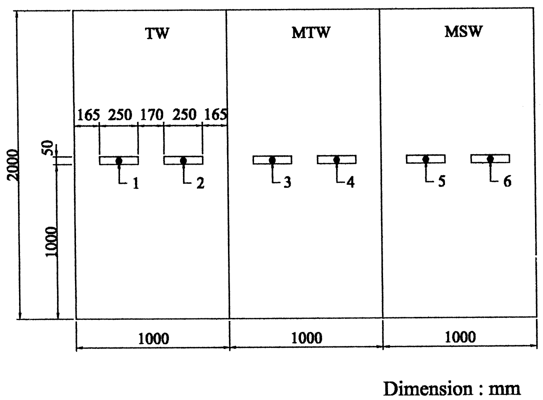


Fig. 5. Measured positions on each type of walls with inlet openings at 1 m above floor. (△) Air temperature; (●) air velocity.

3.2. Induced number of air changes

Due to the buoyancy driven force, the air is continuously induced through the house with a rate that depends, mainly, on intensity of incident solar radiation. Fig. 9 shows an example of hourly variation of induced air flowrate. The small difference between measured incoming air and outgoing air indicate good accuracy of measurement.

The corresponding induced number of air changes varied between 10 to 15. This quite high air change rate led to a lower indoor temperature, resulting from a reduction in the rate of heat stored within the house.

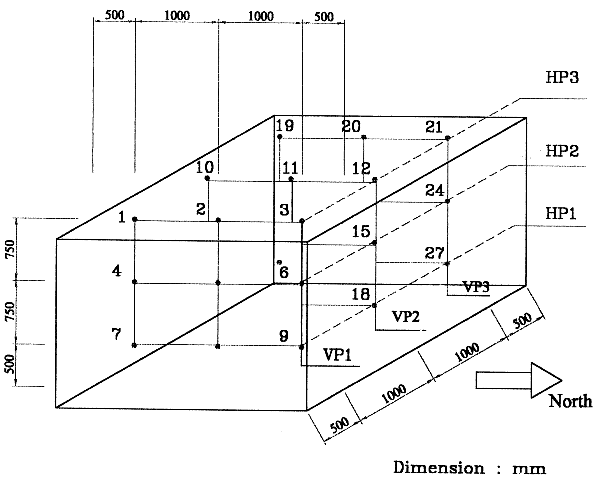


Fig. 6. Positions of air temperature and velocity measurement inside the house and the vertical and horizontal planes.

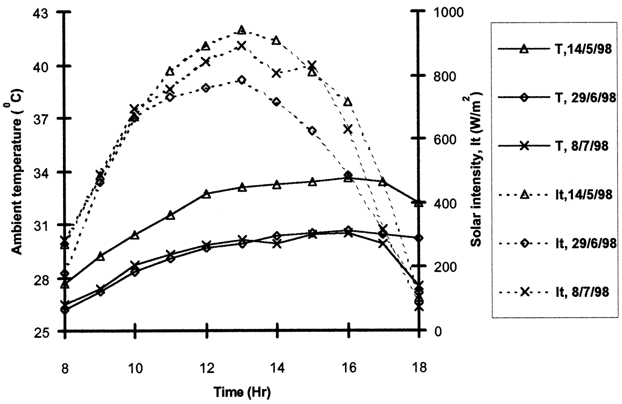


Fig. 7. Ambient conditions during the days of experiments.

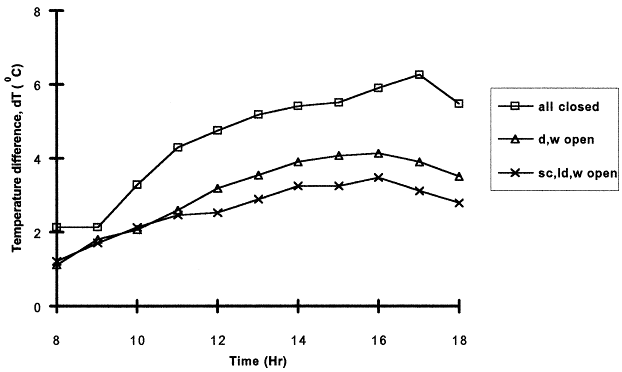


Fig. 8. Comparison of the difference between average room and ambient temperatures for different room conditions. (□) All openings closed on May 14, 1998; (△) door and window opened on June 29, 1998; (×) solar chimney (SC area = 6 m^2), lower door and window opened on July 8, 1998).

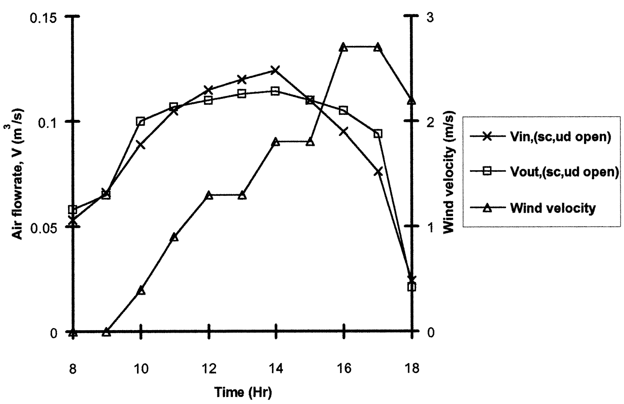


Fig. 9. The induced incoming and outgoing air flowrate through the room (SC area = 6 m^2, lower door and window opened on July 8, 1998).

Table 2
Indoor air temperature and velocity fluctuation inside the house (SC area = 6 m^2, upper door opened on June 20, 1998)

Plane number	Time: 10 AM		Time: 2 PM	
	Temperature (°C)	Velocity (m/s)	Temperature (°C)	Velocity (m/s)
Vertical 1 (V1)	31.92	0.06	35.28	0.09
Vertical 2 (V2)	31.90	0.04	35.37	0.05
Vertical 3 (V3)	32.01	0.02	35.47	0.03
Horizontal 1 (H1)	32.01	0.02	35.26	0.02
Horizontal 2 (H2)	32.02	0.04	35.41	0.06
Horizontal 3 (H3)	31.80	0.06	35.46	0.08

3.3. Thermal comfort

For a free running building, the two main thermal comfort parameters are the temperature and velocity of room air. From Section 3.2, we found that with 6–9 m^2 surface area of solar chimney, the indoor temperature is about 2–3°C above that of ambient, which is relatively acceptable provided that there is sufficient air motion to decrease resultant temperature. Table 2 shows that the average air velocity near the door (plane V1, see Fig. 6) was the highest one, because of the incoming outdoor air through the upper door opening (the lower door and window grills were closed). At plane V3, the air velocity was too small as there are no openings. Along horizontal planes, the air velocity increased with increasing vertical height. Thus, at the living level, around 1 m above floor, there is continuous air motion induced by the buoyancy-driven force resulting from the four solar chimney ventilators used here. Regarding thermal comfort, the induced air motion of about 0.04 m/s cannot satisfy occupants as with temperature of about 35–37, a higher air velocity is needed, about 2 m/s [10]. This air motion could be increased by increasing the number of units of solar chimneys on roof, eastern and western walls and by installing several free openings at the northern facade of room.

4. Conclusion

With four solar chimney ventilators of surface area of only 6 to 9 m^2 — corresponding to a ratio of 0.24–0.36 m^2/m^3 (SC area to house volume) — the average rate of ventilation (ACH) between 12 AM to 2 PM was about 15, corresponding to 1.6 to 2.5 time/h per unit surface area of solar chimney. This induced ventilation reduced room overheating, expressed by a relativeness index defined as the temperature difference between average room temperature and ambient, by about 50%; Room temperature was about 2–3°C above ambient.

Regarding thermal comfort, the induced air motion of about 0.04 m/s at the living level, around 1 m above floor, cannot satisfy occupants as with indoor temperature of about 35–37°C, a higher air velocity is needed. This air velocity could be increased by increasing the surface area of solar chimney.

Finally, it is our opinion that natural ventilation seems to be feasible and viable. This, of course, awaits a large-scale testing in order to see how effective such a ventilation system would be in a real building.

Acknowledgements

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