Experimental Studyof Passive Solar Cooling in Hot Arid Regions Using Trombe Walls with Humidification

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*Abstract:-*The present paperinvestigates one environmentally appealing and a cheap method to reduce the heat gain from solar radiation impinging on buildings in summer time. A Trombe wall system and an evaporative cooling unit are incorporated in a test room to enhance natural ventilation from room to the outside and to reduce the interior temperature of the test room respectively. The temperature measurements at different locations inside the test room showed a remarkable reduction in temperature inside the test room compared with the ambient temperature. The results obtained encourage using incorporated systems for buildings in hot regionsto accomplish comfort for residents and reduce the bill of electricity.

*Key-Words: -*Trombe wall, solar chimney, passive cooling, evaporative cooling

1 Introduction

The energy crisis increases from day to day and the struggles to obtain oils as one of the most energy recourses are still continued. This forced the researchers and scientists to find out new and exploited alternative resources of energy. The energy consumption for air conditioning in buildings represents a considerable ratio of the total energy consumption in the buildings. Therefore, the presence of other methods of air cooling for buildings is an important requirement. Trombe Wall is one solution as it provides passive cooling. Its use can lead to a reduction of the energy consumption in buildings for hot regions where air cooling is necessary. A Trombe wall is a south-facing masonry wall covered with glass spaced a few millimetres away. Sunlight passes through the glass and is absorbed by the wall. The wall has two vents near its bottom and top while a third vent is in the roof at the top of the air gap for air circulation. A fraction of the energy absorbed in the masonry surface warms up the wall.The rest is transferred by convection to the air gap and the room and by radiation to the glass. The outside surface of the wall is painted black to increase its absorption capacity; while the inside surfaceof the Trombe wall can be insulated to reduce heat transferred by convection to the room. Natural ventilation can be created through a vent at thebottom of the wall to allow room air to circulate into the air gap by the effect of the buoyancy and escapes to the outside via the vent at the top of the air gap. At the same time coolair can be drawn to the room through a vent (see Fig.1). Trees may be planted on the side of the building where outside air is introduced to room to provide shade to reduce the temperature of the outside air entering the room. Although it is a very well-known system and widely studied, management of solar energy, its heat and fluid flows mechanisms and the design consideration of the system of Trombe walls including fabrication materials to optimize the ventilation process need more experiments and research [1]. The interest in passive solar cooling has been increased in the last years, mainly for economic and environmental reasons [2, 3]. Guohui [4] showed that by using Trombe walls for summer cooling, the ventilation rate increases with the increase of wall surface temperature solar heat gain, wall height and thickness. The ventilation rate also increases with increasing the air gap width between the wall and glazing. The prospect of global warming has encouraged architects and building engineers to search for ways of heating, cooling and ventilating buildings by passive means rather than energy consuming mechanical devices. Among these is the solar chimney, essentially a solar energy absorber with open top and bottom, which induces airflow through a building when solar radiation impinges on it [5]. The predicted heat transfer rate increases with channel and massive wall surface heat flux [6]. The performance of a glazed solar chimney is influenced by the channel width as well as solar heat gains. Absorption of solar energy from the sun can be increased by using aglazedsurface on the side facing the sun. A material having high absorptivity of solar energy can be used on the opposing side. The size of the solar energy -absorbing surface is more important than the diameter of the chimney. A numerical study of vertical solar chimney for enhancing stack ventilation in buildings has been studied. The predicted ventilation rate increases with solar radiation flux and solar chimney height. A reverse flow can be observed at the outlet when the chimney air gap increased to a certain value [7].

Figure1 illustrates the basic operation of aTrombe wall in summer time operation. Solar radiation that passes through glazing is largely absorbed at the wall surface. The air in the gap between wall and glazing is then heated by convection from the absorber and glazing. The decrease in density experienced by the air causes it to rise, whereupon it is replaced by room's air from below. The rate at which air is drawn through the room depends upon the buoyancy force experienced, (i.e. the temperature differential), the resistance to flow through the gap, and the resistance to the entry fresh air induced to the room. Trombe walls are generally used to provide ventilation principally for heating, but are also used in summer to enhance ventilation. In winter the two vents of the wall are opened and the vent at glass side is closed. In summer, the upper vent of wall is closed and fresh air induced to room passes through the air gap to the outside through the roof' vent. In summer the chimney effect in ventilating the room with air induced through vents in shaded walls causes a cooling effect. In such a case the need of a cooling effect and the supply of solar radiation are in phase. There are many choices to make when designing a Trombe wall, including height, width and depth of gap, type of glazing, type of absorber, and the inclusion of insulation or thermal mass in the wall. In this study, a test room is built and the system of Trombe wall with an evaporative cooling (EV) unit are incorporated in the room to produce comfort in the room during summer Experimental work is designed to test the performance of the designed system.

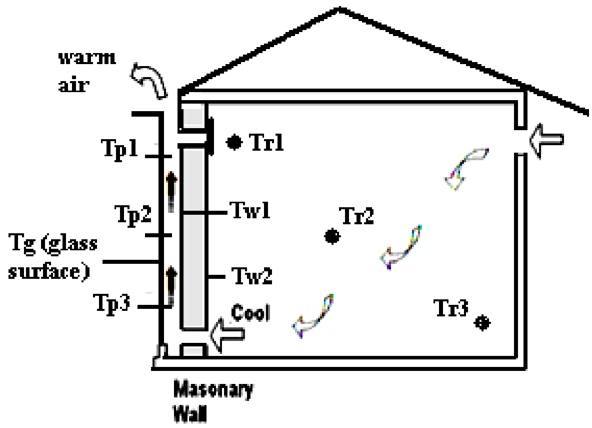

Fig.1 Use of Trombe wall in summer cooling

2. Experimental Work

A Wooden room was builtin the roof of the faculty of industrial education building-Sohaguniversity. One ofits sides,south side, was made of glass and a masonry wall 0.4 m thick was incorporated inside the room facing the glass and forming with it an air gap varied from 0.15 to 0.2 m thickness. The wooden room is internally insulated. Also, an evaporative cooling unit was incorporated in the north wall of the room. The experiments were carried out in the month of July 2011 at the top of building faculty of engineering at times of July month. Measurements of temperatures, velocity and humidity using different instruments were taken at different locations in the room and in the Trombe wall system.

2.1 Experimental Set-Up

The overall dimensions of the wooden room are: 2.5 m (length) x 1.7 m (width) x 2.2 m (height). Figure 2 shows view of the wooden room and the system of Trombe wall. The system of Trombe wall is composed of a masonry wall constructed from brick material havinghigh potentialforthermal storage. The

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airgap between the wall and the glass glazing allows air to circulate from the interior of the test room to ambient for ventilation. The thickness of the air could be varied via moving the glass wall on rollers. The glass wall is made from clear glass having thickness of 5 mm. The glass wall is composed of two parts; each part has dimensions of 2.05 m x 0.57m. There is an upper opening,of dimensions 0.3 m x 0.5m,in the north wall. The openingallows the entryof air intothe room. There is an opening at the top of the air gap channel to allow the air to escape out of the channel to the outside.

Fig.2 General View of the experimental set-up of the test room and the Trombe wall system

2.2 Instrumentation

Figure 3 shows a schematic diagram of the test room and the positions of different measurements.

Measurements of air temperature, humidity and velocity as well as surface temperature were taken at different positions. Temperature measurementsat ten positions, see Fig. 3, were recorded using PT-100 sensor of accuracy ±0.5C (three points in air gap, three points inside test room, one point on the surface of glass wall , two points on the front and back surfaces of masonry wall and one point for measuring the ambient temperature). The sensors of temperature for points at glass and wall and at points in the air gap were protected from sun using small pieces of aluminum foil. Air velocities were monitored at entry of test room and at outlet from air gap, see Fig.3, using an anemometer having an accuracy ± 0. 1m/s. The relative humidity of air was measured at ambient, at interior of test room and at outlet from air gap using humidity of accuracy of 0.2 ± RH.

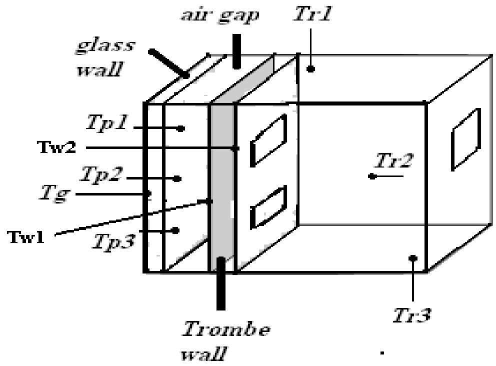

Figure 3 Schematic arrangements of the different temperature measurements locations

2.1 Procedure

Four experiments were carried out, two without evaporative cooling and two experiments with evaporative cooling.

For summer cooling test, the lower vent in the Trombe wall and upper opening in the vertical air gap glazing channel were opened while the upper opening in the wall was closed to allow the air to flow out from the room. The experiments were carried out on July 13, 14, 15 and 16, 2011 at Sohag city- Faculty of Industrial Education. Hourly measurements were taken from 8:00 a.m. to 8:00 p.m. During the period of experiment, hourly measurement of the ambient temperature and the air velocity at inlet to the test room and at outlet from the air gap were also recorded. The evaporative cooling unit was turned on July 15 and 16, 2011. The measurements were recorded every hour.

3. Results and Discussions

The following findings discuss the hourly variation of temperature at ten positions included in the test room of the Trombe wall

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system during the period from 8am to 8pm, as well as the variation of air velocity and relative humidity with and without evaporative cooling.

3.1 Without Evaporative Cooling

3.1.1 Trombe and glass wall temperatures

Fig.4 shows the recorded values of hourly temperature of the front and back surfaces of the masonry wall (Tw_1,Tw_2) respectively, as well as the glass surfacetemperature faces the sun (Tg). The temperature value of the surface temperaturewall (Tw_1) was increased with relatively large gradient up to 2 p.m. then decreased with relatively less gradient afterwards. The temperature of the insulated back side temperature of wall (Tw_2) tends to increase with relatively small gradient up to 6 pm and then starts to decrease afterwards. The high difference in temperature between the front (Tw_1) and back side (Tw_2) is due to the insulation at the back and due to depth of the wall. The wall absorbs solar energy which has a maximum value around noon and then its flux is decreased. The storage of thermal energy in the masonry wall causes the time lag between maximum solar energy flux and maximum surface temperature. The decrease of surface temperature after 2 p.m. causes a decrease in the buoyancy forces of air flow in the gap. This causes the decrease of air temperature to have fewer gradients after 2 p.m.

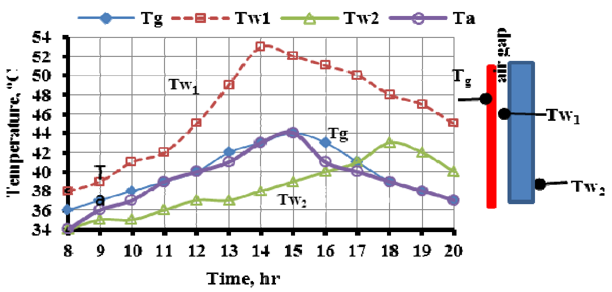

Fig.4 Hourly variation of Trombe wall and glass surface temperatures for an air gap of 50mm (without EV)

3.1.2 Air Temperature inside the Test Room

Fig.5 shows the air temperature profile at three locations inside the test room. The first one is at the upper left corner of the test room, the second at the center of the test room and the third one at lower right corner of the test room. The ambient air temperature is also shown in Fig.5. The air temperatures at the three positions in the test room increase up to 3 p.m., then decrease up to 8 p.m comparing with ambient temperature behaviour. The air temperatures measured inside the test room are lower than the ambient air temperature by a range of about 2 C to 7C.This is mainly due to the relatively low temperature of the inside walls surfaces due to cooling at night hours. The air temperature (T_{r1})at the top left corner was the lowest value compared with the other points up to 1pm. The air temperature (T_{r3})at the lower right corner tends to decrease to the lowest values compared with the other points.

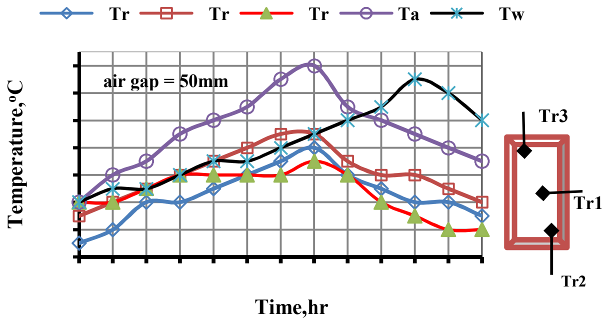

Fig. 5 Hourly variation of air temperature inside the test room (without EV)

3.1.3Air Gap Temperature

Fig. 6 shows the values of air temperature at middle points along the vertical air gap. As expected the valueof air temperature at the top of the air gap has the highest value (stack effect) and the temperature increases along the air gap at all times. It is also noted from Fig.5 and Fig. 6 that the air temperatures in the air gap always greater than temperatures inside the room.

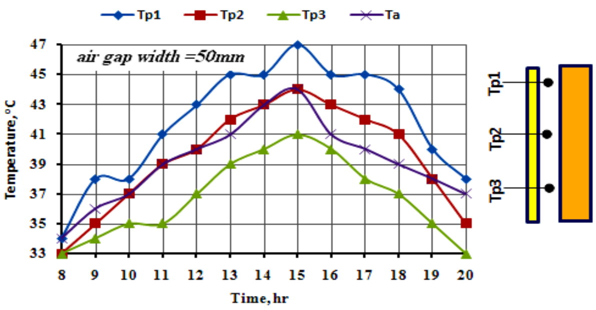

Fig.6 Hourly variaion of air gap temperature along the vertical direction of air gap (with humidification)

3.1.4 Air Velocity and Air Humidity Ratio

Fig.7 shows the hourly variation of air velocity at inlet to the test room and at outlet from the

Trombe wall system. Figure 7 also shows air humidity ratio inside the test room and of the ambient. The value of outlet air velocity (Uo) tends to increase up to 1 p.m.and to decrease afterwards. Velocity at outlet from Trombe wall system(Uo) is higher than the value of inlet air velocity (Ui) to the test room almost all the time. Boyancy action acclerate the air velocity in the period of high solar energy flux. Beyond that period the air velocity tends to decrease due to the decrease in the wall temperature. The values of room air humidity ratio, Hr,have the same trend as the ambient humidity ratio,HR, but with lower values than that of the values of ambient. This isprobably due to the action of the induced ventilation resulting from boyancy forces.

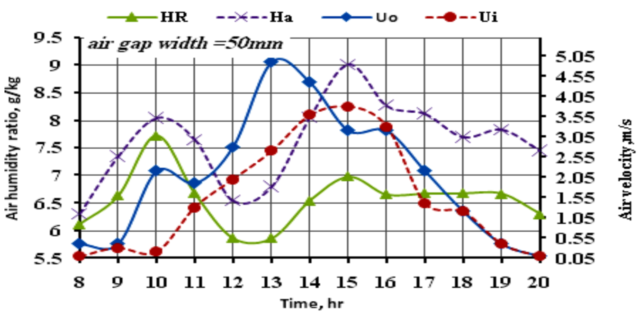

Fig.7. Hourly variation of air velocity and air humidit ratio (without humidification)

3.2 With Evaporative Cooling

3.2.1Air temperature inside the test room

Fig.8 shows the air temperature in the center of the test room (it represents the level at which persons could be presented) for gap width = 50mm, withand without evaporative cooling (EV). As expected, the value of air temperature with EV is lower than that without evaporative cooling. The maximum difference in temperature was about 4°C at 3 p.m. After 3 p.m. the difference was between 2°C and 1°C, while before 3 p.m. ranged between 2°C and 3°C. The decrease of room temperature during operating the evaporative cooling unit is due to the air humidification process. It is to be noted that the increased ventilation due to the Trombe wall decreases the uncomfortable effect of humidity during the operation of the evaporative cooling unit.

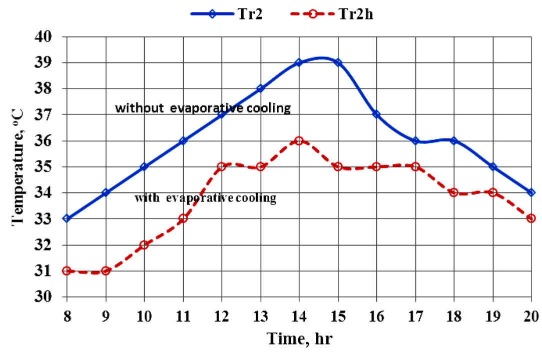

Fig. 8 Comparison the variation of air temperature inside test room with and without EV

3.2.2 Air gap temperature

Figure 9 shows the air temperatures along the air gap with and without EV. As noted for the higher portion of the air gap without EV (Tp_1,Tp_2) are higher than air temperatures with EV ($Tp_{1,h}$, $Tp_{2,h}$) after 11 a.m.

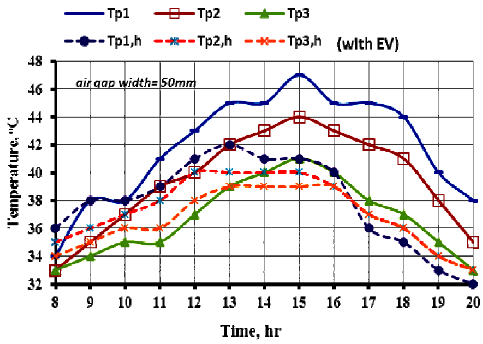

Fig. 9 Hourly variation of air gap temperature with and without evaporative cooling

3.3 Effect of Air Gap Width :

In the following the effect of air gap width on the air temperature variation of the different measurements inside room and along the air gap are discussed for the case with no EV.

3.3.1 Air temperatures inside the test room

Figure 10 shows the hourly variation of air temperature inside the test room for two air gap depth values(50 mm and 100mm). The value of air temperature Tr_2, 50 (air gap depth= 50mm) is higher than Tr2, 100 (air gap depth= 100mm)up to 3 p.m. The value of air temperature Tr_3, 5 (air gap depth= 5cm) is higher than Tr_2, 10 (air gap depth= 10cm) up to 2 pm and then both decrease to almost the same values afterwards. The value of air temperatures Tr_1, 5 and Tr1, 10 are nearly the same. The

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value of Tr3,5 is higher than the value of Tr3,10 up to 2p.m and beyond 2p.m the two values have nearly the same value

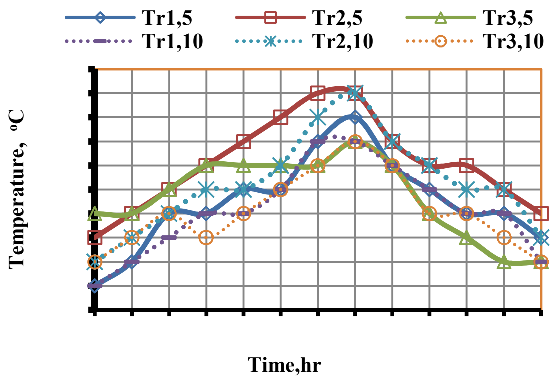

Fig.10 Effect of air gap width on hourly temperature distribution along the air gap

3.3.2 Air gap temperatures

Figure13 shows comparison of the hourly variation of air gap temperatures (Tp_1, Tp2, Tp3) for two air gap widths 50mm, 100mm without EV. As noted, the value of air gap temperatures Tp_1, Tp_2 and Tp_3 for the two air gap widths 50mm, 100mm increases up to time between 2pm and 3p.m .Then tends to decrease afterwards. The values of air gap temperature Tp_1,5 and Tp_1,10 almost has the same value during the period of the experiment. The value of Tp_2, 10 is higher than the value of Tp_2,5 . The value of Tp_3, 10 is higher than the value of Tp_3, 5.

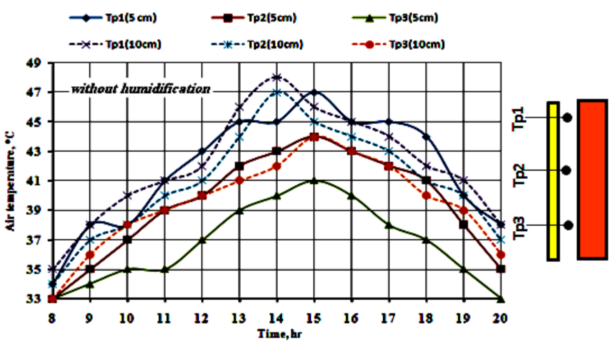

Fig. 11 Comparison of the hourly variation of air gap temperatures for two air gap widths 5cm, 10 cm

3 Conclusions

In the present work, the temperature measurements were taken inside the test room, in the air gap, on the glass and massive wall of a Trombe wall room incorporated system. The air velocity at inlet of test room and out of the air gap is recorded during the period of experiments (8 am to 8 pm).

An important aspect could be obtained from the present work:

- A remarkable reduction in temperature inside the test room through using Trombe wall compared with ambient temperature.
- Addition enhancement could be obtained through using evaporative cooling of ambient air introduced to the room and the ventilation process in this case prevents the accumulation of humidity inside the test room.
- Accumulation of humidity through using the evaporative cooling could be minimized with the induced ventilation.

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