ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 4, October 2014

Experimental Study of Solar Chimney for Ventilation in Hot Arid Region

Ali N. Alzaed and Hany A. Mohamed
College of Engineering, Taif University, Taif, 888, Saudi Arabia

Abstract*— This research experimentally studies the performance of a solar chimney to induce natural ventilation inside a test room placed in arid region. The room was made from wood material except the south wall, Trombe Wall; it is composed from a commercial glass wall apart from masonry thick wall with a small gap. The experimental observations show using solar chimney can maintain the room at lower temperature than the ambient with small variations along the day period. Along the day period it was seen the values of the air velocity using air gap of 5 cm width higher than when using air gap of 10 cm width. The performance of solar chimney with air gap of 5 cm width is more appropriated compared with solar chimney with air gap of 10 cm width. Thus, this system can be recommended to remove undesirable interior heat pollution from a building and provide thermal comfort for the occupant. This encourages using the proper design of a Trombe Wall for buildings in hot regions.

***Index Terms*—Trombe Wall, Solar Chimney, Natural Ventilation.**

I. INTRODUCTION

Today, natural ventilation is not only regarded as a simple way 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 hot region. Depending on the ambient conditions, natural ventilation can is lead to indoor thermal comfort without mechanical cooling being required. The solar chimneys principle is simple: the sun heat gives to passing air, which expands going into a gap between the glass and masonry wall, according to the buoyancy principle: "hot air rises". By this way the air is drawn from the room through the bottom hole achieving the ventilation process. Solar chimney with Trombe Wall provides passive cooling and it can lead to a reduction of the energy consumption in buildings for hot regions. In the solar chimney, due to the difference in density between cool air and warmer air, warm air tends to move upward and escape due to its lower density. This air movement can lead to a stack effect driven by buoyancy. As long as there is a continuous source of heat and a considerable amount of cool air available, a constant stream of air is produced. The higher in the temperature difference and the height of the building cause a greater buoyancy force. This leads to greater air movement. Many configurations of solar chimneys were used widely in the past and many are being developed again today [1]–[4]. Several studies were carried out in this topic [5]–[8]. Four configurations of solar chimney were built by using common construction materials: The Roof Solar Collector [5], the Modified Trombe [6], the Trombe Wall [7] and the Metallic Solar Wall [8]. The interest of passive solar cooling was increased in the last years, mainly for economic and environmental reasons [9], [10]. Using a Trombe Walls for summer cooling, the ventilation rate increases with the increase of surface wall temperature [11]. A solar energy absorbed with open top and bottom, when solar radiation impinges on the building, was studied by [12]. The predicted heat transfer rate increases with channel and massive wall surface heat flux [13], [14]. A reverse flow can be observed at the outer when the chimney gap increased to a certain value [15]. 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 are need more experiments and research [16]. In this study, a test room is built and the system of Trombe Wall is incorporated to the test room. Experimental work is designed to simulate and test the performance of a Trombe Wall incorporated to the test room for cooling processes. The effect of air gap width on both the test room temperatures and the induced ventilations are studied.

II. EXPERIMENTAL WORK

The room was made from wood material except the south wall, Trombe Wall; it is composed from a commercial glass wall apart from masonry wall, 40 cm thick, with a small gap. This side represents a system of Trombe Walls and glazing oriented to the south direction for capturing the solar gain during the sun time. The wooden room is well internally insulated. Tests are performed without the aid of humidification process. The experiments are carried out on summer at arid valley. Measurements of temperatures, velocity and humidity using different instruments were monitored at different locations in the room and in the Trombe Wall system.

A. Experimental Set-Up

Figure 1 shows a Photographic picture of the wooden room with the Trombe Wall. The overall dimensions of the wooden room are 2.5 m (length) x 1.7 m (width) x 2.2 m (height). The system of Trombe Wall oriented composed from a masonry wall constructed from brick material having potential to thermal storage for solar transmitted, 40 cm width. A glass wall is stand in the front of the masonry wall at a defined space, air gap. This gap allows air to circulate from the test

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 4, October 2014

room interior to the ambient for ventilation. The distance between glass wall and masonry wall, gap width, can be changed by moving the glass wall on rollers. There is an upper opening window, 0.3 m x 0.5 m, in the north wall facing to the Trombe Wall. This opening window allows the entry of air into the room. The glass wall is commercial clear glass with 5 mm thickness. The glass wall is composed of two parts, upper part has 57 cm height and the down has 2.05 m height. This makes an opening at the top of the air gap channel to allow the air escaping out from the solar chimney. Figure 2 shows a schematic drawing of the general view of the wooden room with the Trombe Wall. Measurements of air temperature, humidity, and velocity and surface walls temperature were taken at different positions as in Fig. 2. Temperatures were measured at eight different positions, as in Fig. 2, using PT-100 sensors of accuracy ±0.5C (three points in air gap, one point on the middle of 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 wall and at points in the air gap were protected from sun using small pieces of aluminum foil. Air velocities through the air gap were measured using an anemometer with accuracy ± 0.1 m/s. The relative humidity of air at ambient and interior of the test room was measured using humidity device of accuracy of 0.2 ± RH. The measurements were taken from 8:00 am to 8:00 pm every hour.

Fig. 1: Photographic picture of the test room.

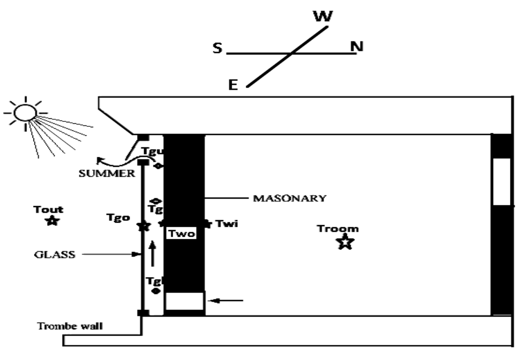

Fig. 2: Schematic drawing of the test room

III. RESULTS AND DISCUSSIONS

All measured temperatures along the day hours, (room, Troom, inside masonry wall, Twi, outside masonry wall, Two, gap upper space, Tgu, gap middle space, Tgm, gap bottom space, Tgb, outside glass, Tgo, and ambient, Tout, Temperatures), for air gap widths of 5 cm and 10 cm are given in Figs 3 and 4 respectively. The variation of these temperature values along the day hours approximately linear increase to a peak value at 14 o'clock then approximately linear decrease till 8 o'clock as shown in Figs 3 and 4. These variations are normally expected according to the basics of heat transfer and heat incident by the sun irradiation. It is also clearly shown that the room temperature remain lowest than the ambient with small variations along the day period due to use the solar chimney. The effects of the air gap width are discussed below.

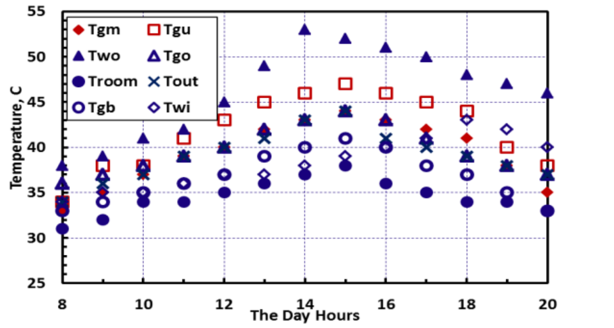

Fig.3: All measured temperatures along the day hours at 5 cm air gap width.

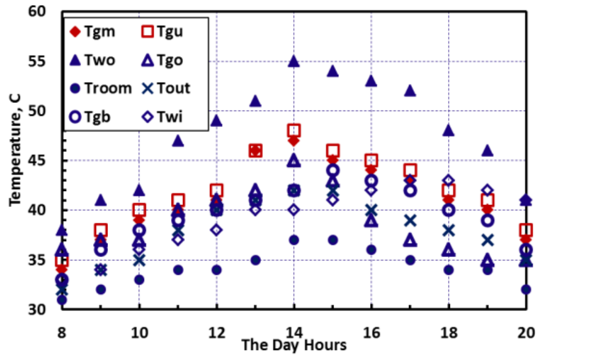

Fig.4: All measured temperatures along the day hours at 10 cm air gap width.

A. *Variation of Air Gap Temperatures*

Figures 5 and 6 show the variation of air temperatures through the solar chimney, air gap, along the day hours compared with the corresponding masonry wall outer temperatures and ambient temperatures for gap widths of 5 cm and 10 cm. It is clearly shown that the air temperatures through the gap gradually increase from the bottom to the upper position (Tgb < Tgm < Tgu) for gap widths of 5 cm and 10 cm. This observation agrees with the buoyance law. So, stream flow of air through the chimney gap would be created from the bottom to the upper causing through air gap. Therefore, air naturally flows from the room to the gap creating ventilation process. The figures also show remarkable increase at the outside masonry wall temperature, Two, compared with the ambient, Tout, and the air gap temperatures, (Tgu, Tgm, Tgb). This remarkable increasing at the outside wall temperature increases the conduction heat transfer through the masonry wall. From the other hand this

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 4, October 2014

increases in the wall temperature may assist for increasing the air flow velocity through the gap causing an enhancement in the room ventilations. Thus well insulated the back side of the masonry wall should be done for the solar chimney.

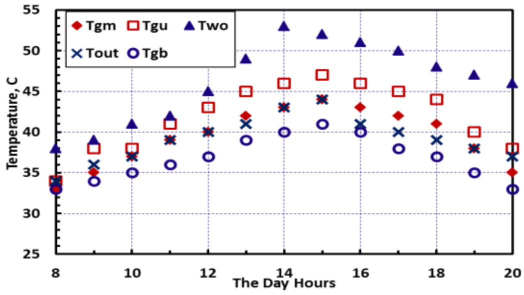

Fig.5: Measured temperatures through the air gap along the day hours at 5 cm width.

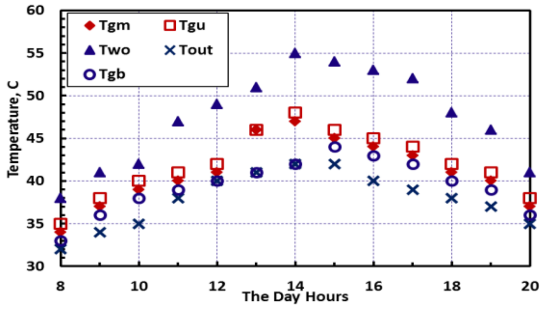

Fig.6: Measured temperatures through the air gap along the day hours at 10 cm width.

B. Variation of Masonry and Glass Wall Temperatures

Figures 7 and 8 show the measured values of ambient, Tout, air gap, Tgm, outer wall, two, inner wall, Twi, and room temperatures, Troom, temperatures at the chimney middle level along the day hours. These figures are mainly presented to show the remarkable reduction in the conduction heat transfer, Two >> Twi, due to well insulated of the back side of the masonry wall. This show that the present experimental test rig was built with accepted quality.

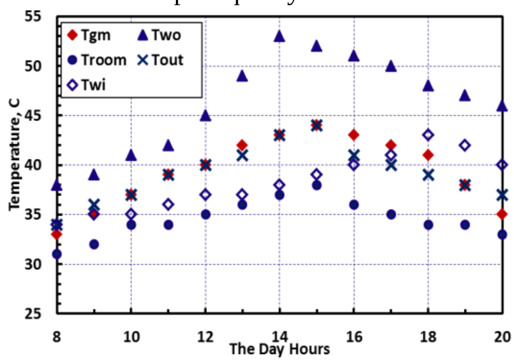

Fig.7: Measured temperatures at the chimney middle level along the day hour at 5 cm air gap width.

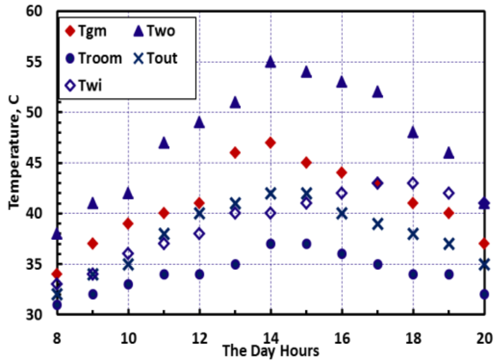

Fig.8: Measured temperatures at the chimney middle level along the d ay hour at 10 cm air gap width.

C. Variation Air Velocity through the Solar Chimney

The variation of air velocity through the solar chimney, Vgap, and the corresponding Tout, Tgm, Two, and Troom measured temperatures along the day hours are shown in Figs 9 and 10. It is clearly shown for 5 cm gap width as in Fig. 9, gradually increase of the air velocity till 15 o'clock then gradually decrease till 19 o'clock after that it is gradually increase to 20 o'clock. It is also clearly shown for 10 cm gap as in Fig. 10, gradually increase of the air velocity till 16 o'clock then gradually decrease till 18 o'clock after that it is slightly increase to 20 o'clock. The increasing and decreasing the air velocity is attributed due to the buoyancy action resulted from increase and decrease the chimney temperatures. This observation ensures the ability of the solar chimney to create a ventilation process through the test room. Along the day period it can be seen the values of the air velocity using gap width 5 cm higher than when using gap width 10 cm. This leads that the use of gap width 5 cm achieves better ventilation compared with the use of gap width 10 cm.

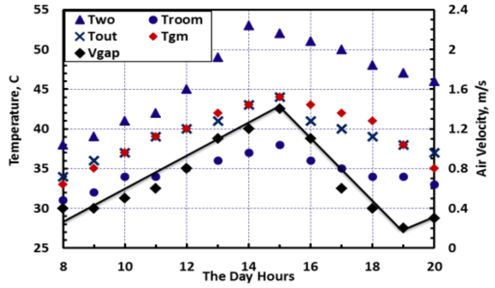

Fig. 9: Solar chimney air velocity, Vgap, Tout, Tgm, Two, and Troom along the day hours at 5 cm air gap width.

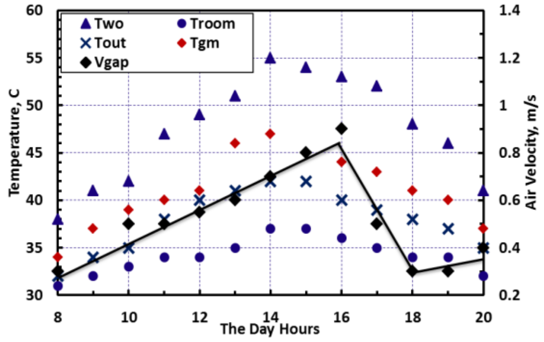

Fig. 10: Solar chimney air velocity, Vgap, Tout, Tgm, Two, and Troom along the day hours at 10 cm air gap width.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 4, October 2014

D. Variation of Air Relative Humidity inside the Room

Figures 11 and 12 show the air relative humidity inside the test room, Rhi, compared the ambient relative humidity, Rho, along the day hours for air gap widths of 5 cm and 10 cm. It is clearly shown more reduction in room relative humidity by using air gap of 10 cm width. Since the ambient air relative humidity is too low for that required for human comfortable, so solar chimney with 5 cm air gap is the better.

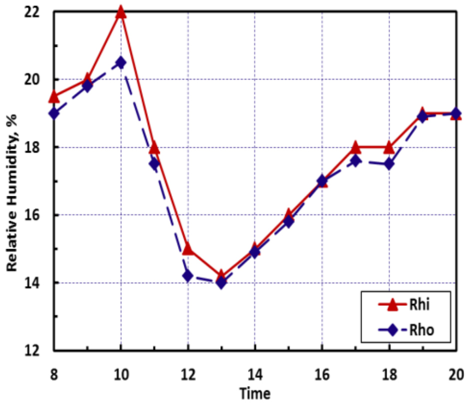

Fig. 11: Measured temperatures along the day hour at 5 cm air gap width.

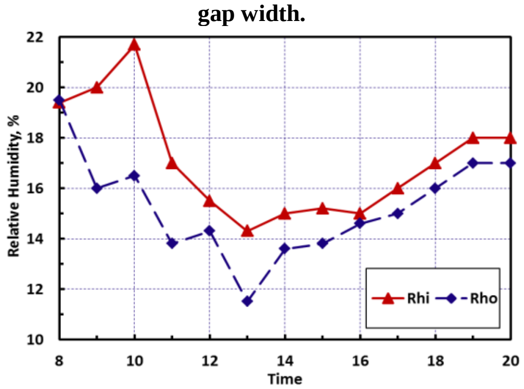

Fig. 12: Measured temperatures along the day our at 10 cm air gap width.

E. Variation of the Heat Transfer Rate

Figures 13 and 14 show the air temperatures profile along the heat transfer path, Tout, Two, Twi, and Troom along the day hours. Since the heat transfer area and the coefficients of the heat transfer approximately remains constant during all the experimental measurements due to small differences in the air velocity along the heat path. Therefore, the temperatures difference the ambient and room temperatures, (Tout-Troom) represent about the heat transfer through the whole. So, Fig. 15 represents the heat transfer through the whole system along the day hours for air gap of widths of 5 cm and 10 cm. It is shown that the heat transfer rate using solar chimney of gap width 10 cm reaches to its peak value before using gap width of 5 cm by two hours. This means, the room temperatures are faster affected by the ambient temperatures for solar chimney with air gap of 10 cm width compared with that of 5 cm width. So, solar chimney with air gap of 5 cm air gap width is recommended.

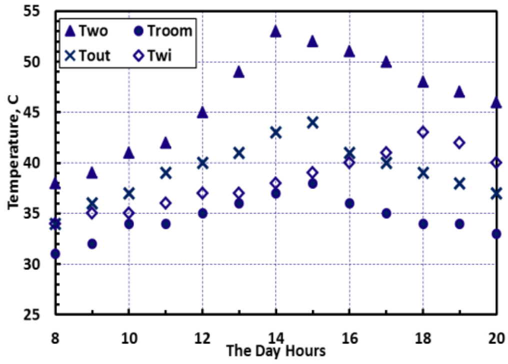

Fig. 13: Measured temperatures along the day hour at 5 cm air gap width.

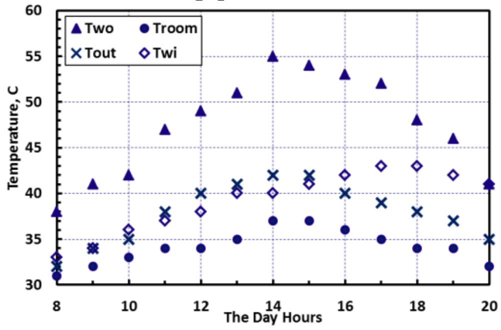

Fig. 14: Measured temperatures along the day hour at 10 cm air gap width.

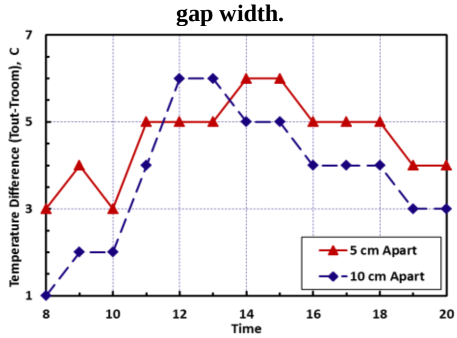

Fig. 15: Measured temperatures along the day hours.

IV. CONCLUSION

Important aspects can be realized from the present work:

1. The remarkable reduction in the conduction heat transfer, Two >> Twi, due to well insulated of the back side of the masonry wall shows that the present experimental test rig was built with accepted quality.
2. Using solar chimney can maintain the room at lower temperature than the ambient with small variations along the day period. So, thermally comfortable indoor environment for many hours during hot summers can be achieved.
3. A natural ventilation system that improves air quality and thermal comfort levels in a single story building can be created by using solar chimney. Use solar chimney with air gap 5 cm width achieves better ventilation compared with the use of air gap 10 cm width.
4. The performance of solar chimney with air gap of 5 cm width is more appropriated compared with solar chimney with air gap of 10 cm width.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 4, October 2014

REFERENCES

[1] H.B. Awbi, “Design consideration for naturally ventilated building”, Renewable Energy Int. J., Vol. 5, Part 2, pp. 1081–1090, 1994.

[2] G. Gan, “A parametric study of Trombe Wall for passive cooling of buildings”, Energy and Buildings, Vol. 27, pp. 37–43, 1998.

[3] N.K. Bansal, “Solar chimney for enhanced stack ventilation”, Building and Environment, Vol. 28, No. 3, pp. 373–377, 1993.

[4] A.K. Sharma, N.K. Sodha, and M.S. Gupta, “Very-thermal wall for cooling / heating of buildings in composite climate”, Int. J. Energy Res. Vol. 13, No. 6, pp. 733–739, 1989.

[5] J. Khedari, J. Hirunlabh, and T. Bunnag, “Experimental study of a roof solar collector towards the natural ventilation of new houses”, Energy and Buildings Vol. 26, No.2, pp. 159–164, 1997.

[6] J. Khedari, C. Lertsatitthanakorn, N. Pratinthong, and J. Hirunlabh, “The modified Trombe Wall: a simple ventilation means and an efficient insulating materials”, Int. J. Ambient Energy, pp. 104–110, 1998.

[7] J. Khedari, S. Kaewruang, N. Pratinthong, and J. Hirunlabh, “Natural ventilation of houses by a Trombe Wall under the climatic conditions in Thailand”, Int. J. Ambient Energy, Vol. 20, No. 2, pp. 85–94, 1999.

[8] J. Hirunlabh, W. Kongduang, P. Namprakai, and J. Khedari, “Study of natural ventilation of houses by a metallic solar wall under tropical climate”, Renewable Energy Int. J., Vol. 18, pp. 109–119, 1999.

[9] A. Ruiz, J.M.Salmeron. F.Sanchez, R.Gonzalez and S.Alvarez, “A calculation model for Trombe Walls and its use as a passive cooling technique”, International Conference”, Passive and Low Energy Cooling for the Built Environment, Santorini, Greece, May 2005.

[10] Huseyin Onbasioglu, and A.Nilufer Egrican,”Experimental approach to the thermal response of passive systems”, Energy Conversion & Management, Vol. 43, pp. 2053-2065, 2002.

[11] Guohui Gan,”A parametric study of Trombe Walls for passive cooling of buildings”, Energy and Buildings, Vol. 27, pp.37-43, 1989.

[12] D.J. Harris and, and N. Hewing, "Solar chimney and building ventilation”, Applied Energy Vol. 84, pp. 135–146, 2007.

[13] Y Li, X Duanmu, Y Sun, J Li and H Jia,”Study On the Air Movement Character in Solar Wall System”, Proceedings: Building Simulation, 2007.

[14] Fereshteh Tavakolinia “Wind-Chimney, Integrating the Principles of a Wind-Catcher and a Solar-Chimney to Provide Natural Ventilation” MSc, the Faculty of California Polytechnic State University, San Luis Obispo, December 2011.

[15] Wang Liping and Li Angui,"A numerical study of vertical solar chimney for enhancing stack ventilation in buildings", The 21th Conference on Passive and Low Energy Architecture. Eindhoven, The Netherlands, September, pp. 19 - 22, 2004.

[16] Alvaro Ruiz-Pardo, Servando Alvarez Dominguez, and Juan Antonio Sanz Fernandez, “Review : Revision of the Trombe Wall calculation method proposed by UNE –EN ISO 13790”, Energy and Buildings, Vol. 42, pp. 763-773, 2010.