

# Experimental Investigation on Performance of Trombe Wall Passive Solar Technique for Buildings Cooling In Arid Regions

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**ABSTRACT:** In this study, the performance of a Trombe Wall for building cooling processes in arid regions is investigated experimentally. A test room is made, and the system of Trombe Wall is incorporated into the test room. Within the experiments, the effect of air humidifier on both the test room temperatures and the induced ventilations are carried out. A test room was made from wood material except the south wall, Trombe Wall; it is composed of a commercial glass wall apart from thick masonry wall with 5 cm gap. The experiments were carried out on summer in the arid region along the day hours with and without humidification process. The experimental results show a reduction in room temperature, reaches up to 8 C°, with small variations along the day period. Therefore, the indoor environment thermal comfortable for many hours during hot summer day are achieved. The experimental results show an increase in natural air ventilation, with air velocity reaches to 1.8 m/s. Therefore, this system can be recommended indoor air quality and provide thermal comfort for buildings the occupant.

**KEYWORDS:** Trombe Wall, Solar Chimney, Natural Ventilation

## I. INTRODUCTION

For acceptable indoor air-quality levels, natural ventilation is not only considered to provide the required fresh air for the building's occupants but also; it can be considered as an energy saving tool that affects in reducing the internal cooling load of housing located in the hot region. Natural ventilation is changing the airflow in the area without using a mechanical device. The effective forces that drive and influence on natural ventilation are the wind in building openings or stack effect like a solar chimney as shown in Fig. 1. In the solar chimney, there is airflow through the stack caused by the generated air movement as the air temperature increases its density decreases and causes its flow upward. In particular, environments, proper use of natural ventilation can be lead to indoor thermal comfort without the need of a mechanical cooling machine. This due to that the air movement during the ventilation process led to improve the indoor human thermal comfort by replacement of hot, humid air surrounding the occupants with cold fresh air moreover improves the air quality by reducing the impurity [1]. As a result, the air is drawn from the room through the bottom opening achieving the ventilation process. The Trombe Wall with Solar chimney provides passive cooling, and it can lead to a reduction of the energy consumption in buildings in hot regions. As long as there is a continuous source of heat addition in the flow channel and a considerable amount of cold air at around the building is available, a constant stream of airflow inside the building is produced. As the temperature difference is increased and integrated with the height of the building, which causes a greater buoyancy force that leads to more significant air movement. Many configurations of solar induced flow passages were used widely in the past, and many are being developed now a today [2–5]

Evaporative coolers cool the air, and they are suitable for hot, arid regions [6]. Air washer, humidifier, roof surface evaporative cooler [7], and passive downdraft evaporative cooler [8] are few examples of evaporative coolers. Water, which is cooled in evaporative coolers, can be used to cool spaces with the aid of cooling system [9]. Thermal comfort achieving using evaporative

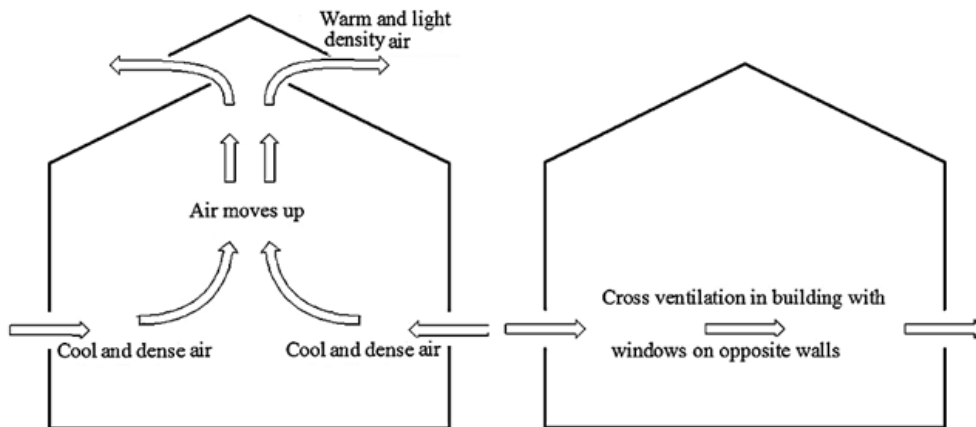


Fig. 1: Schematic drawing shows induced ventilation (left) and cross ventilation (right).

Cooling has been studied extensively [8, 10]. A passive evaporative cooler as reported in [8] achieved average moreover, peak indoor temperatures 5 °C and 10 -14 °C lower than the average and peak outdoor temperatures during the summer month of April, an annual energy saving of 64% over conventional air conditioning and 36% saving in maintenance expenses. Evaporative coolers can be coupled with other passive systems like earth tunnel cooling [11] and ventilation cooling [12] for better performance.

The solar chimneys principle is that the heat source the solar radiation incident on the outer surface of the chimney that absorbed and converted into heat transfer to the air inside the chimney which expands and moves according to the buoyancy principle: "hot air rises". Several studies were carried such as [13–16]. Four configurations of the solar chimney were built by using conventional construction materials: The Roof Solar Collector [13], the Modified Trombe[14], the Trombe Wall [15], and the Metallic Solar Wall [16].

For passive solar cooling applications, research and developments increased in the last years, mainly for economic and environmental reasons [17, 18]. Studies on using a Trombe Walls for summer cooling indicate that the ventilation rate increases with the increase of wall surface temperature [19]. Solar energy absorbed with an open top and bottom Trombe wall design, combined with solar radiation incident on the building walls was studied by [20]. Another study that predicted the heat transfer rate increases with the channel and the massive wall surface heat flux is done by [21, 22]. While [23] reported that, a reverse flow is observed at the outlet as the chimney gap increased to a particular value. Although it is a very well-known system and widely investigated, management of solar energy, the generated heat, fluid flows mechanisms, with design consideration of the system of Trombe Walls that include fabrication materials for optimization of the ventilation process still there is a need for more experiments and research [24].

In this study, the performance of a Trombe Wall for building cooling processes in arid regions is investigated experimentally by constructing a test room, with a Trombe Wall incorporated into this room. Within the experiments, the effect of air humidifier on both the test room temperatures and the induced ventilations are carried out.

## II. EXPERIMENTAL WORK

The experimental test room was made from wood material except the south wall, Trombe Wall that is composed of a commercial glass wall apart from thick masonry wall, 40 cm, with a small gap of 5 cm. This room side represents a system of Trombe Walls and glazing oriented to the south direction for capturing the solar gain during the sunshine hours. The wooden room is well internally insulated. Experimental tests are performed with and without the aid of humidification process. The experiments are carried out on summer time in the arid valley. Temperatures, velocity, and humidity measurements by using different instruments that monitored at various locations in the room and the Trombe Wall system.

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(An ISO 3297: 2007 Certified Organization)

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## Experimental Set-Up

The overall dimensions of the room are 2.5 m (length) x 1.7 m (width) x 2.2 m (height) and from the wood. The system of Trombe Wall oriented composed of a masonry wall constructed from a brick material having the potential to thermal storage for solar transmitted, 40 cm width. A glass wall is stand in the front of the masonry wall at 5cm space, and air gap. The air gap allows air to circulate from the test room interior to the ambient for ventilation. There is an upper opening window dimension of, 0.3 m x 0.5 m, in the north wall that face the Trombe Wall. The glass wall is composed of two parts, the top has 57 cm height, and the down has 2.05 m height making an opening at the upper part of the air gap channel to allow the air is escaping out from the solar chimney. A water washer humidifier located through this window. The opening window permits the entry of air into the room. The glass wall is clear commercial glass with 5 mm thickness. The effect of the air gap width on both the test room temperatures and the induced ventilations are studied in [25].

Figure 2 shows a schematic of the general view of the room with the Trombe Wall. The room was located on the roof of the college of engineering solar laboratory at Taif University, Al-Haweiah -Taif, Saudi Arabia. Tests were run separately. Air temperature, humidity, velocity, and surface walls temperature measurements were done at different locations as shown in Fig. 2. The Temperatures were measured at eight different positions using PT-100 sensors of accuracy  $\pm 0.5^\circ\text{C}$ . (three points in the air gap, one point in the middle of test room, one point on the surface of the glass wall, two points on the front and back surfaces of a masonry wall and one point for measuring the ambient temperature). The sensors of temperature for points at glass wall and points in the air gap were protected from the sun by using small pieces of aluminum foil. While, the air velocities through the air gap were measured using an anemometer with accuracy  $\pm 0.1$  m/s. In addition, the relative humidity of air at ambient and interior of the test room was measured using humidity device of the accuracy of  $0.2 \pm \text{RH}$ . The measurements were taken from 8:00 Am to 8:00 Pm every hour.

## III. RESULTS AND DISCUSSIONS

Temperature measurements is carried out along day hours, (room,  $T_{\text{room}}$ ,  $T_{\text{wi}}$ , inside masonry wall, outside masonry wall,  $T_{\text{wo}}$ , gap upper space, gap middle space,  $T_{\text{gu}}$ ,  $T_{\text{gb}}$ , outside glass,  $T_{\text{go}}$ ,  $T_{\text{gm}}$ , gap bottom space, and ambient,  $T_{\text{out}}$ , Temperatures), for cases with and without humidification process that are presented in Figs 3 and 4 respectively. The variation in the temperature values along the day hour's is approximately increasing linearly to the peak value at 14 o'clock then almost linear decrease until 8 o'clock as shown in Figs 3 and 4. These variations are expected according to the basics of heat transfer and the incident solar radiation. It is clearly demonstrated that the room temperature kept lower than the ambient with small variations along the daytime due to use the solar chimney, while, the effects of the humidification process will be discussed below. In addition, these two figures show a bigger reduction in the room temperature in the case with humidification process. The results in the case with humidification show a decrease in the room temperatures reaches to  $8^\circ\text{C}$ , and the room temperatures remain approximately constant during the day hours.

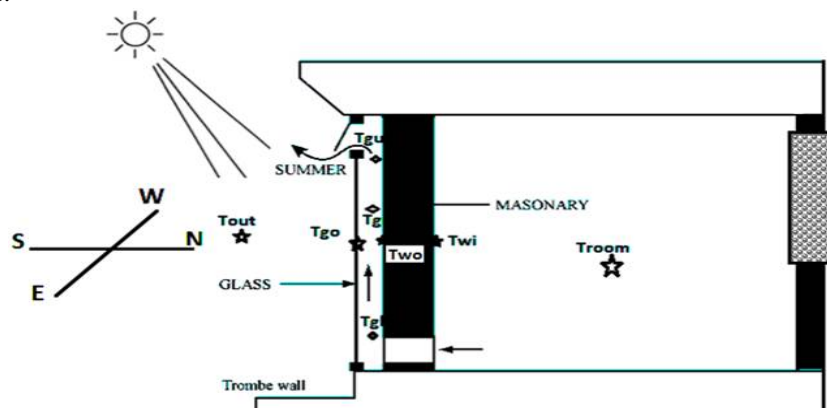


Fig. 2: Schematic drawing of the general view of the test room with the Trombe Wall.

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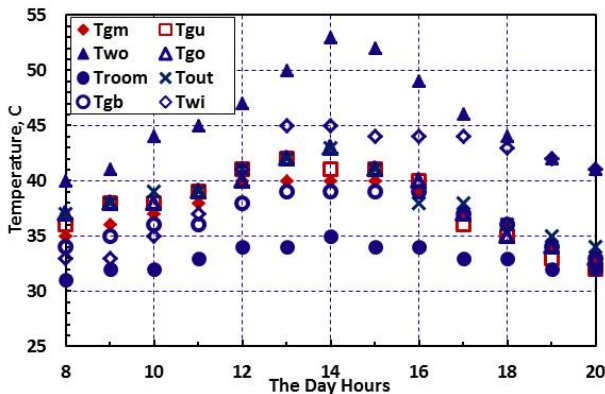


Fig.3: Temperatures measured values during the day hours with humidification process.

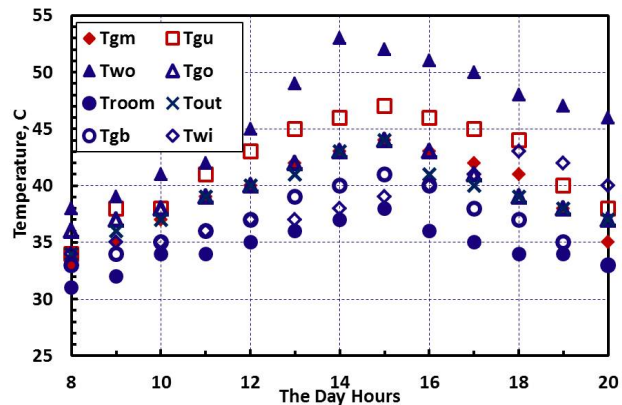


Fig.4: Measured temperatures values along the day hours without humidification process.

## Variation of Air Gap Temperature

Figures 5 and 6 show the temperatures change for the air through the solar chimney, air gap, through the day hours compared with the corresponding values of the masonry wall outer temperatures and ambient temperatures with and without humidification process. It is clearly shown that the air temperatures through the gap gradually increase from the bottom to the upper position ( $T_{gb} < T_{gm} < T_{gu}$ ). This observation agrees with the buoyancy law. Therefore, stream flow of air through the chimney gap would be created from the bottom to the upper casing through the air gap. Thus, the air flows naturally from the room to the gap creating the ventilation process. The figures also show a remarkable increase in  $T_{wo}$  (the outside masonry wall temperature) compared with the ambient temperature values,  $T_{out}$ , and the air gap temperatures, ( $T_{gu}$ ,  $T_{gm}$ ,  $T_{gb}$ ). This remarkable increasing at the outside wall temperature increases the conduction heat transfer through the masonry wall. From the other hand, this increase in the wall temperature may assist for increasing the airflow velocity through the gap leading to an enhancement in the room ventilations. Therefore, well insulation of the masonry wall backside should be done for the solar chimney. On the other hand, in the case of the humidification process, it is noticed lowering in the air temperatures through the chimney gap with small rising in temperatures from the bottom to the upper. One can see  $T_{gu} > T_{out}$  in the case without humidification this means a restriction to the air flow from the chimney gap. While  $T_{gu} \leq T_{out}$  in the case with humidification and more free flow of ventilated air can be expected in this case.

## Masonry and Glass Wall Temperatures variations

Figures 7 and 8 show measured values of the ambient air,  $T_{out}$ , air gap,  $T_{gm}$ , an outer wall,  $T_{wo}$ , an inner wall,  $T_{wi}$ , and room temperatures, as well as  $T_{room}$ , temperatures at the chimney middle level through the day hours. These figures mainly show the remarkable reduction in the conduction heat transfer,  $T_{wo} \gg T_{wi}$ , due to well insulated of the backside of the masonry wall which apparently proof that the present experimental test rig was built with accepted quality.

## Variation Air Velocity through the Solar Chimney

The variation of air velocity through the solar chimney,  $V_{gap}$ , and the corresponding  $T_{out}$ ,  $T_{gm}$ ,  $T_{wo}$ , and  $T_{room}$  measured temperatures along the day hours are shown in Figs 9 and 10. It is clearly shown in the case with humidification as in Fig. 9, gradually increase the air velocity until 16 o'clock, and then gradually decrease until 20 o'clock. While in the case without humidification as in Fig. 10, it can be seen a gradual increase of the air velocity till 15 o'clock then gradually decrease till 19 o'clock after that it is gradually increased to 20 o'clock. The increase and decrease in the air velocity are attributed due to the buoyancy action resulted from the increase and decreased the chimney temperatures. This observation ensures the ability of the solar chimney to create a ventilation process through

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the test room. Along the day period, it can be seen the values of the air velocity using humidification process higher than in the case without humidification. The experimental results also show an increase in natural air ventilation, with air velocity reaches to 1.8 m/s.

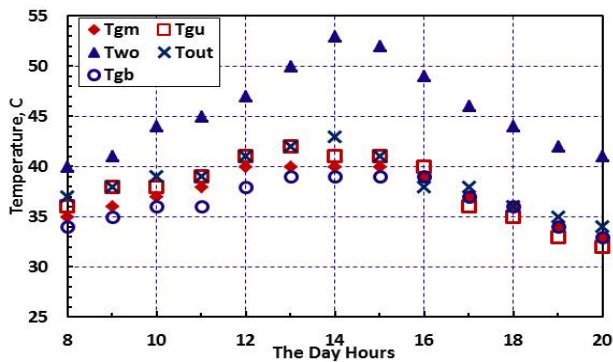


Fig.5: Measured temperatures values through the air gap along the day hours with humidification process.

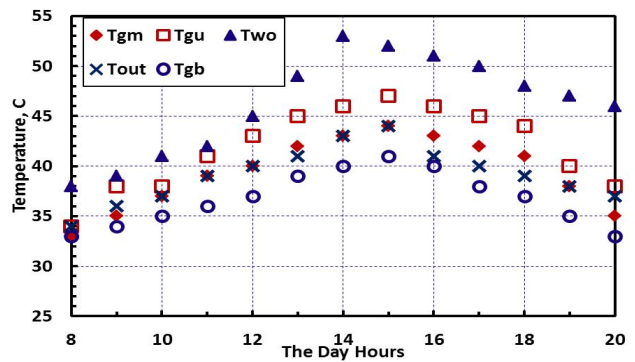


Fig.6: Measured temperatures values through the air gap along the day hours without humidification process.

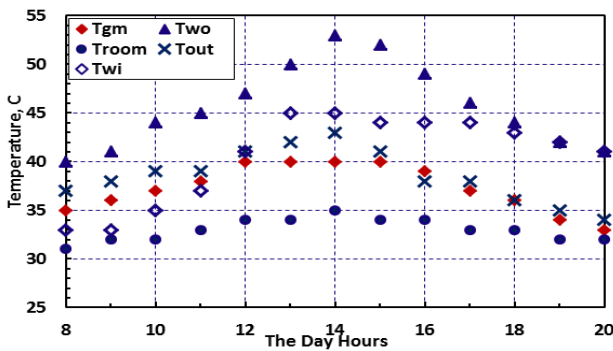


Fig.7: Measured temperatures values at the chimney middle level along the day hour with humidification process.

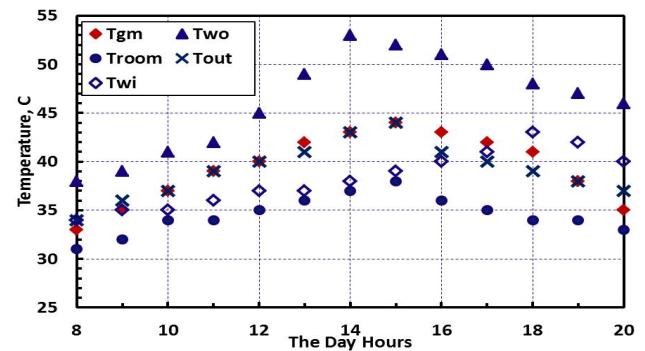


Fig.8: Measured temperatures at the chimney middle level along the day hour without humidification process.



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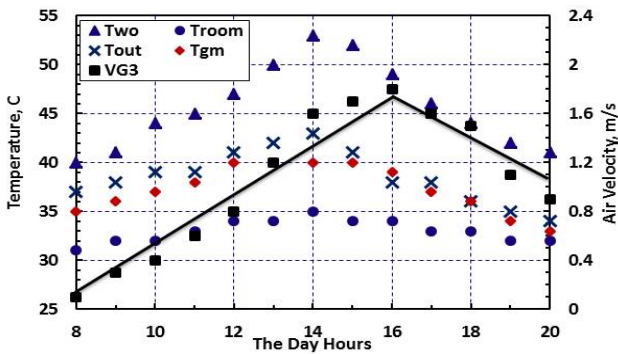


Fig. 9: Solar chimney air velocity,  $V_{gap}$ ,  $T_{out}$ ,  $T_{gm}$ ,  $T_{wo}$ , and  $T_{room}$  along the day hours with humidification process.

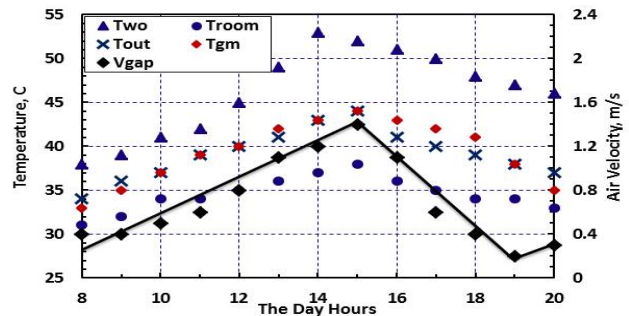


Fig. 10: Solar chimney air velocity,  $V_{gap}$ ,  $T_{out}$ ,  $T_{gm}$ ,  $T_{wo}$ , and  $T_{room}$  along the day hours without humidification process.

## Variation of Air Relative Humidity inside the Room

Figures 11 and 12 show the air relative humidity inside the test room,  $R_{hi}$ , compared the ambient relative humidity,  $R_{ho}$ , along the day hours with and without humidification process. It is clearly shown higher increase into room relative humidity in the case with humidification process. Since the ambient air relative humidity is too low, thus humidification process should be recommended for human comfortable.

## Variation of the Heat Transfer Rate

Figures 13 and 14 show the air temperatures profile through the heat transfer path,  $T_{out}$ ,  $T_{wo}$ ,  $T_{wi}$ , and  $T_{room}$  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 between the outer and inner side of the masonry wall temperatures,  $(T_{wo}-T_{wi})$  represent the heat transfer rate to the room. Therefore, Fig. 15 is adapted to represent the heat transfer rate to the room during the day hours in the both cases with and without humidification process. It is shown that the heat transfer rate using humidification process higher than in the case without humidification till 10 o'clock then it goes down to the remain of day hours. However, this means the room temperatures are faster affected by the ambient temperatures for the solar chimney in the case without humidification most the day hours. On the other hand, the difference between the ambient and the room temperatures are higher in the case of humidification process than without humidification till 15 o'clock then it goes down as shown in Fig. 16. This reduction in the temperatures difference may be attributed to the relative humidity values as shown above in Fig. 11. As a result, it can be concluded that using solar chimney with humidification process can be recommended for achieving passive cooling.

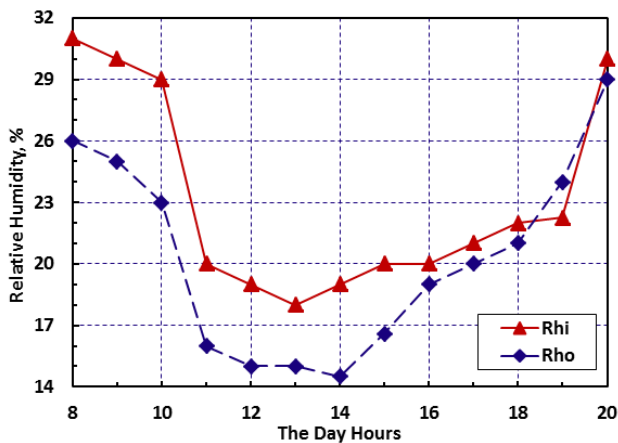


Fig. 11: Measured the air relative humidity inside the room along the day hour with humidification process.

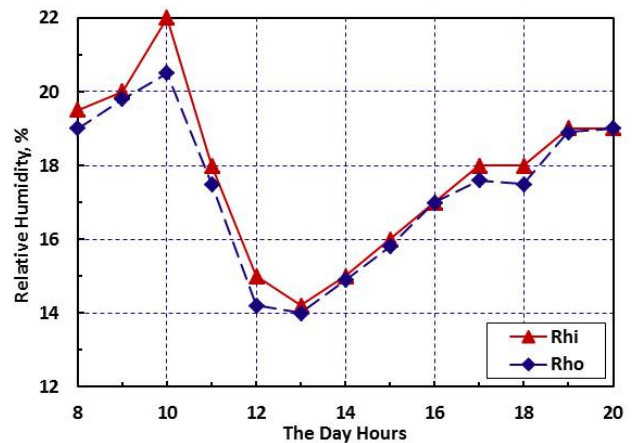


Fig. 12: Measured the air relative humidity inside the room along the day hour without humidification process.

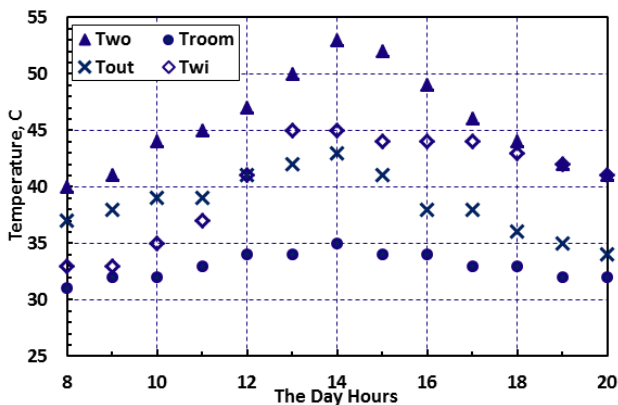


Fig. 13: Measured temperatures along the day hour with humidification process.

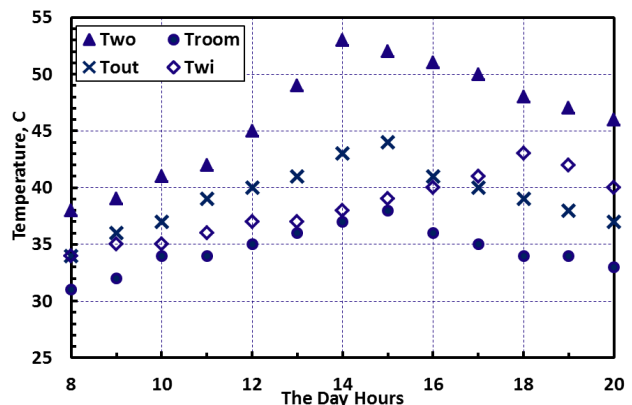


Fig. 14: Measured temperatures along the day hour without humidification process.

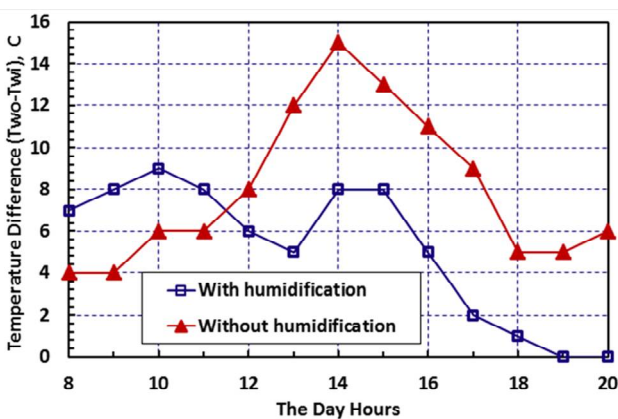


Fig. 15: Measured temperatures difference along the day hours.

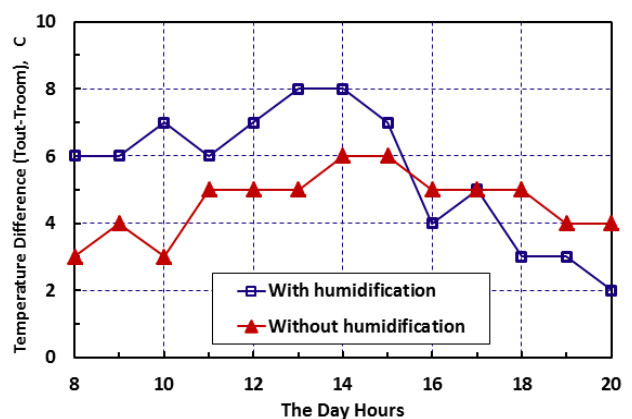


Fig. 16: Measured temperatures difference along the day hours.

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## IV. CONCLUSIONS

In this study, the performance of a Trombe Wall for building cooling processes in arid regions is investigated experimentally. A test room is constructed with the system of Trombe Wall incorporated into the room. Within the experiments, the effect of air humidifier on both the test room temperatures and the induced ventilations are carried out. Important aspects can be realized from the present work are follows:

1. The remarkable reduction in the conduction heat transfer is achieved  $Two \gg Twi$ , due to well insulated of the backside of the masonry wall.
2. The results show that the inner room temperature can be maintained at a temperature lower than outside the ambient temperature with difference reaches to  $8^{\circ}\text{C}$ , with small variations along the day period. Therefore, indoor environment thermal comfortable can be achieved.
3. The experimental results show an increase in natural air ventilation, with air velocity reaches to 1.8 m/s. Thus, a natural ventilation system that improves air quality and thermal comfort levels in a single story building can be created by using this technique.

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