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Utilization of the Trombe Wall in Hot Climate Regions: Jordan as a Case Study

Ali M, Othman, Adnan I. O. Zaid

Abstract— The Trombe wall is an ancient technique which still continues to serve as an effective feature of a passive solar system, In this paper, the previous designs of Trombe walls are presented and discussed and their advantages and limitations for their utilization in hot climate regions are also discussed. Furthermore, the main points to be considered in the design of an efficient and cost effective Trombe wall with special focusing on its utilization in hot countries are presented and discussed. Finally, two new designs of Trombe walls for hot countries like Jordan which is presented as a case study in the paper are presented and discussed. The manufacturing, implementing and testing of these systems are in progress ad the obtained results will be published in due course.

Index Terms— Trombe wall, Utilization, Hot climate regions, Jordan, Case study.

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1 Introduction

THE Trombe wall is an old system which incorporates a thermal storage and delivery systems. Historically, in the late 1950s, this system was named after the French scientist, Felix Trombe by a Trombe wall Ref.[1]. Essentially, the Trombe wall consists of a massive wall, made of stone, brick, or concrete, with high inertia and black color installed at a small distance from a glazing partition as illustrated in Fig.1. The massive wall absorbs solar radiation and transmits part of thermal energy into the required building by natural convection through the solar chimney formed by the glazing partition on one side and the wall on the other. The working mechanism is described in ref. [2] as follows: the external surface of the massive wall absorbs the heat from the sun which is conducted slowly through it to the inner surface and finally passes to the room by convection.

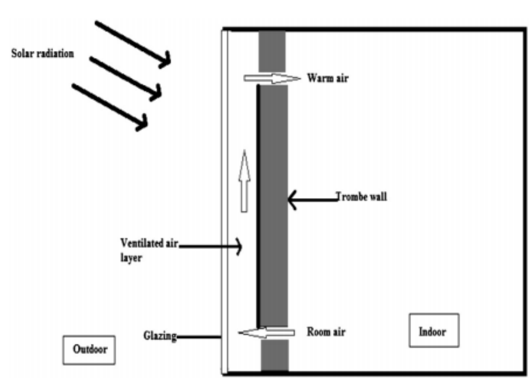

Fig. 1. Functioning principle of the Trombe wall

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To increase the possibility of use of Trombe walls in hot climates, the design of the Trombe wall should be modified so that it can be operated in different modes in order to minimize conduction heat gains through the storage wall and to maximize the heat removal from the interior by ventilation process.

The design of the Tombe wall system was modified by in Ref. [3] and its schematic drawings are shown in Figs. 2 (a) and 2 (b) for working in winter and summer respectively.

Date	the slat angle	Fan (open /close)
January 14th,2014 and January 15th,2014	0°	close
December 20th,2013 and December 23rd,2013	45°	close
January 2nd,2014 and January 3rd,2014	90°	close

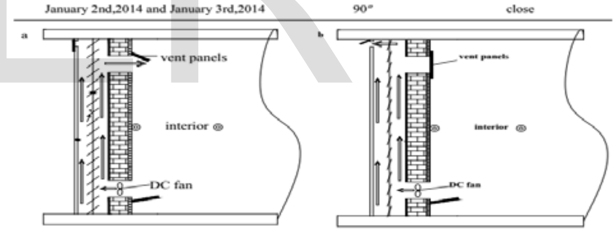

Fig. 2. (a) the work of trombe wall in winter; (b) the work of Trombe wall in summer

It can be seen from Fig. 2 that three modes are specified namely: mode (a), mode (b) and mode (c) each has a specific function. Mode (a) accumulates the heat in the heavy mass storage wall during radiation falling. Mode (b) is used to remove the excess of energy from the storage wall in order to reduce the undesirable effect of heat conduction which passes to the interior part of the wall. Mode (c) is useful for the storage energy or solar radiation. It is worth noting in this respect to note that this system with its three modes is not expected to work unless the exterior temperature is lower than that of the interior one, [3]. These three modes when included in a Trombe wall system have shown great potential for integration into low energy consumption buildings. However there are still problems regarding their designs and application, for example to improve heat accumulation of the massive wall in winter, some researchers install an absorber plate in the air gap and use a black surface of the heat storage wall in order to decrease the direct heat gain from solar radiation and prevent overheating in summer time and also to increase the heat accumulation and preservation in winter, [3].

Although this type of Trombe wall showed a great potential for integration into low energy consumption buildings. However there are still problems regarding their application and design, for example to improve the heat accumulation of the massive wall in winter time. To overcome this problem, some researchers have installed an absorber plate in the air gap and used a black surface of the heat storage wall. However, the black wall has the discrepancy of causing overheating in summer. These two problems of decreasing the direct heat gain from solar radiation and preventing the overheating phenomenon in summer time and increasing the heat accumulation and preservation effect in winter are still to be solved.

Nowadays, due to the heating, ventilating and air conditioning (HVAC), building energy consumption is growing up. Therefore it is essential to make greater use of the renewable energy, e.g. solar energy, to provide space heating energy for the buildings. Trombe wall, which is also used as storage wall and solar heating wall (SHW) is regarded as a feasible and sustainable technology of the solar utilization in buildings due to its simple configuration, high efficiency and little or zero running cost. It is made up of a masonry wall with high thermal inertia and black color, an air gap and an outside glazing. The masonry wall is equipped with two vents at the top and the bottom for the air thermo-circulation between the air gap and the indoor space. The earlier research demonstrated that it could reduce a building's energy consumption up to 30%. Several researchers have conducted theoretical and experimental work on these aspects of the Trombe wall, [4]. Their results showed important benefits, even though further dynamic analysis need to be carried out. As a matter of fact the real benefit of phase change materials, PCMs, integration does not only have the advantage in the reduction of thermal storage mass weight, but it is mainly linked with the different behavior of these smart materials under dynamic solar radiation exposure. Other researchers explored the potential benefits of integration of PCMs in external heavy envelopes with integrated solar walls, through the execution of in-site tests on mock-up cubicles. The results showed how, also in heavy constructions, benefits connected with implementation of PCMs could be significant and up to 17% of energy saving could be expected. Also recent in-site tests are showing the benefits of PCMs integration in modified Trombe walls, useful for existing building energy retrofitting. All these experimentations show the importance of an appropriate choice of material typology and position for different climates. Therefore the general aim of their research is to provide a comparative assessment of thermal comfort variability deriving from several PCMs integrated into the internal partition of a Trombe wall when exposed to cold, mild and hot climates, [5].

This study focuses on the thermal behavior of Trombe walls in summer and their contribution to indoor thermal comfort and energy performances of residential buildings.

Classical Trombe wall is a passive solar system made up of a facing massive wall painted black on the external surface, an air layer and glazing on the exterior. The wall is equipped with two vents one at the top and the other on at the bottom.

The Trombe wall continues to serve as an effective feature of passive solar design system, [1].Trombe wall has been widely studied for winter behavior, for cold climates. In summer behavior actions to improve summer behavior can be grouped into three categories: ventilation, shadings and insulation.

Solar shading of Trombe wall in summer roller shutters and insulation curtains between glass and masonry wall layer are included for the optimum design of Trombe wall system in a Mediterranean region [6].

Another classical Trombe wall is shown in Fig.2. Essentially, it consists of a massive wall, generally made of stone, brick, or concrete, with high inertia and black color installed at a small distance from a glazing. The wall absorbs solar radiation and transmits part of thermal energy into the building by natural convection through the solar chimney formed by the glazing on one side and the wall on the other. The heat absorbed from the sun by the external surface of the wall is conducted slowly through the massive wall to the inner surface and then to the room by radiation and convection. The advantage of the important heat capacity of the wall, is storing heat from the sun during the day and releasing it into the building space during the night [2].To increase the possibility of use of Trombe walls in hot climates. This element can be operated in different modes in order to minimize conduction heat gains through the storage wall and to maximize heat removal from the interior by the ventilation.

Nowadays due to the heating, ventilating and air conditioning (HVAC), building energy consumption is growing. It is essential to make greater use of the renewable energy, e.g. solar energy, to provide space heating energy for building. Trombe wall, which is also known as storage wall and solar heating wall (SHW) , is regarded as a feasible and sustainable technology of the solar utilization in building due to its simple configuration, high efficiency and of little or zero running cost. It is made up of a south-facing black color masonry wall with a high thermal inertia and an air gap with an outside glazing.The masonry wall is also equipped with two vents one at the top and the other at the bottom for the air thermo-circulation between the air gap and the indoor space. The earlier researchers demonstrated that this type of Trombe wall could reduce up to 30% of the building's energy consumption. Later, researchers got engaged in the theoretical and experimental aspects of the Trombe wall, [4].

A comparative assessment of thermal comfort variability derived from several PCMs integrated into the internal partition of a Trombe wall exposed to cold, mild and hot climates was carried out and the obtained results are given in Ref. [5].

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The available literature reveals that different types of Trombe walls were investigated. These are: (1) a classic and modified Trombe wall; (2) a zigzag Trombe wall; (3) a solar water wall; (4) a solar trans wall; (5) a solar hybrid wall; (6) A Trombe wall with phase-change material; (7) a composite Trombe wall; (8) a fluidized Trombe wall; and (9) a photovoltaic Trombe wall. These types were reviewed and discussed in

Ref. [6]. The last type, (the photovoltaic Trombe wall) was reported that it can provide approximately 20% of a house's heating demand.

PCMs' integration in lightweight building components is highly beneficial and able to minimize the fluctuation of temperatures (both radiant and operative) due to the lack of thermal storage mass. These beneficial effects are even more evident if the thermal flux is forced by solar radiation, which is an extremely variable heat source. Previous studies demonstrated the benefits of PCMs integration in Trombe walls in different climatic areas, but an integrated parametrical assessment was needed, in order to evaluate the effects of materials' properties and integration strategies in several climatic areas. In all climatic areas, the adoption of PCMs contributes also to increase the depraving between

absorbed and released thermal fluxes by the partition, restoring thermal inertia to lightweight constructions. [5]

Thermal parameters of Trombe wall in real occupancy conditions occupation were selected to compare the thermal behavior of Trombe wall (occupied and unoccupied). Temperatures and heat fluxes of Trombe walls were compared for with and without occupants. Air temperature is higher when the occupants are inside the room, due to the internal heat gains. As the temperature difference between wall surface and room air is lower when the occupants are present, heat flux density is lower in this case. The screened Trombe wall absorbs heat when the room temperature is higher than surface temperature (afternoon) and release it when the room temperature is lower (morning and night times), giving an important contribution in maintaining the room temperature constant, [6].

2 Main Considerations in the design of a Trombe Wall

To have an efficient and cost effective design of a Trombe wall the following points should be taken into consideration:

1. Decide on the type of the system whether it is vented or unvented system.
2. Use of fans: it was found that walls with a thermostatically controlled fan improves the performance of Trombe walls by up to 8%.
3. Insulation.: proper thermal insulation is necessary for maximizing the ventilation rate of a building with Trombe walls. Thermally the interior of Trombe walls should be thermally insulated both in winter and summer which will improve the efficiency of the system.
4. The area of the Trombe wall: the ratio of the Trombe wall area to the total wall area has been proposed as an important parameter in evaluating the Trombe wall efficiency,
5. The wall thickness: generally, the optimal thickness of a Trombe wall is related to latitude, climate and heat loss. It contributes to the effectiveness of Trombe walls.
6. Materials: type, color, and coating materials, are among the important parameters which should be considered in the design of a Trombe wall because they attribute to the heat storage, convection and conduction; hence affects the wall's efficiency. Increasing the weight and volume of Trombe walls increases the storage capacity of the walls.
7. The glazing specifications: the type: normally it is either single or double glazing. The latter improves the Trombe-wall performance. Similarly, the glazing material, its thickness and the number of the glazing layers are also very important factors. In Canada, Richman and Pressnail introduced a new type of glazing, which uses a low-e coating film sprayed over spandrel glass. The glazing increases the efficiency of Trombe walls by reducing radiation.

If these points are considered in the design of a Trombe-wall system and based on an economic perspective by considering the Trombe wall as a matter of costs and benefits will render the designed system cost effective besides the additional benefits to the clients for example the amount of energy conservation and CO_2 reduction.

3 Suggested Models of a Trombe wall

Based on the climate conditions in hot countries in general and Jordan in particular and taking into consideration the points mentioned in the previous section two models of Ttrombe walls are suggested and shown in Figs. 3 and 4. Usually thermal insulation function is to reduce heat transfer to or from buildings, (especially in hot climate regions) in spite of that still a certain quantity of heat flow inters of leaves the buildings through walls in summer or winter seasons. The following figure shows an idea is suggested to describe how to prevent the heat flow from entering of leaving the building. In summer mode the solar heat radiation will be cached by liquid layer (may be water) then heated water will be circulated to a lower temperature or can be used for domestic purposes. This arrangement is suitable for new or old existing buildings. In winter mode heat loss from buildings to the surroundings will be absorbed by suggested system and will be delivered to hot water supply cistern or boiler suction side to increase the inlet temperature.

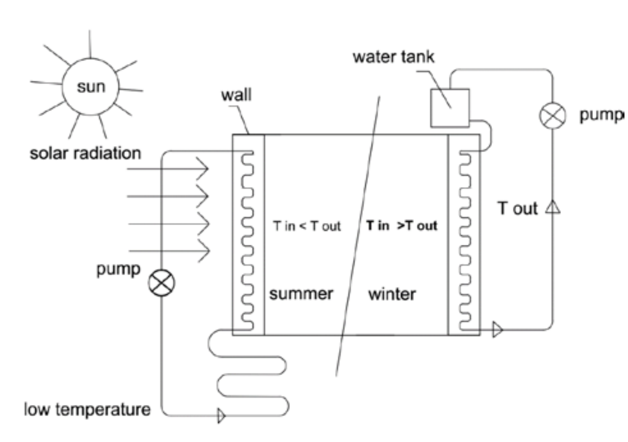

Fig. 3. Suggested model of Trombe wall number (1)

As it is known that thermal insulation could not prevent heat flow in or out of the buildings, this suggestion is based on the idea that water steam has very low thermal conductivity, so by using the already existing heat pipes in buildings to heat water for domestic purposes, those pipes could evaporate a certain quantity of water to form a blanket steam layer as an insulator to prevent the solar radiation heating buildings walls and ceilings, this arrangement is very suitable for hot climate regions in summer season.

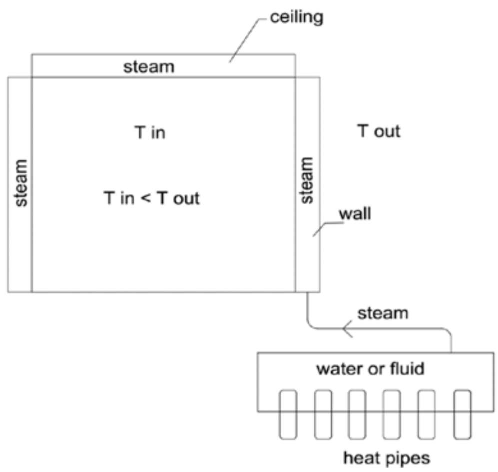

Fig. 4. Suggested model of Trombe wall number (2)

4 Application of Trombe Wall to Jordan; a Case Study

Jordan has abundant supplies of solar energy, with relatively high average daily solar radiation of 5.5 kW h/m2 day, since it lies in the "global Sunbelt" between 29 11and 33 22N latitudes. The annual sunshine is more than 300 days On the other hand, mentioned that incorporating passive solar designs can reduce heating and cooling load and improve comfort. Trombe wall system was first developed in 1881 by Edward Morse [an American scientist and later was revived by the French inventor Felix Trombe in late fifties (Duffie and Beckman, 2006). Trombe wall is made of a material that absorbs a lot of heat, such as concrete or masonry coated with a dark black colored thin material, (Duffie and Beckman, 2006), which will be placed behind an acing glass curtain to increase the thermal mass and to receive high amounts of solar gain. The heat absorbed from the sun is conducted slowly through the storage mass to the inner surface. The air heated by convection rises and passes into the heated space. During the period when there is no sun light, the heat stored in the thermal mass wall will radiate and pass to the space which needs to be heated. The thermal energy can be transferred to the room by air circulating through the gap between the wall and the glazing partition through openings at the top and bottom of the wall. Circulation can be natural convection controlled by dampers placed on the vent openings or by forced circulation using fans. A solid storage wall can be considered as a set of nodes connected together by a thermal network, each with a temperature and capacitance.

4 Conclusions

From the research work of this paper, the following points can be concluded:

i). Integrating phase change materials, PCMs, is at its beginning although the obtained results are very promising. This research area is worthwhile investigating to find out which materials are appropriate for integration in Trombe wall for hot, moderate and cold regions.

ii). Despite the voluminous amount of published research papers on the Trombe wall over the last sixty years the design and implementation of an efficient and cost effective
Trombe wall which can be utilized in both hot and cold regions is far from being complete and further research work is required.

Acknowledgment

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