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# A review on the application of Trombe wall system in buildings

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ABSTRACT

A major portion of the total primary energy consumed by today's buildings is used in heating, ventilating, and air-conditioning (HVAC). Conventional heating and cooling systems are having an impact on operational cost, energy requirement and carbon dioxide emission. In this regard, Trombe walls are receiving considerable attention because of their potential ability for addressing the environmental and energy crisis. This paper reviews the most pertinent contents of studies on Trombe walls that have been carried out in the recent 15 years. According to utilizing functions of Trombe walls, they are divided into two major types: a heating-based type and a cooling-based type. In terms of content, we emphasize the introduction of three groups of parameters that be considered when designing Trombe walls: the 'Trombe wall' parameters, the 'building' parameters and the 'site' parameters. Then different evaluation indicators on Trombe walls have been summarized from three points of view: energy, environment and economic. We hope that this review is useful to academic researchers and can provide a reference for architects or related engineering designers in the field of passive design.

## 1. Introduction

Parallel to the global population growth, energy consumption and environmental issues are today an increasing and global concern. According to the World Energy Council, primary energy demand will double by 2050 [1]. The building sector is the majority of energy consumption in the world and most of the energy is used for heating, ventilation and air condition systems (HVAC). They are indoor climate controls that regulate humidity and temperature to provide thermal comfort and indoor air quality [2]. For these reasons, the buildings we find today are expected to achieve both energy efficient and environmental-friendly design, using renewable energy partly or completely instead of fossil energy for heating and cooling, particularly solar energy that utilize cost-free solar radiation from the sun. In this direction, the integration of passive solar systems in buildings is one strategy for sustainable development and increasingly encouraged by international regulations. Passive solar techniques can reduce annual heating demand up to 25% [3]. Various architectural devices, such as solar chimneys [4], solar roofs [5], Trombe walls, etc., are used in construction. Among these devices, Trombe walls [6,7], which are known as storage walls and solar heating walls (SHW) [7,8], can harmonize the relationship between humans and the natural environment and are widely used because of advantages such as simple configuration, high efficiency, zero running cost and so on. In addition to being environmentally friendly, using a Trombe wall in building can reduce a building's energy consumption up to 30% [9]. A similar result was presented in Ref. [6]: energy heating savings of 16.36% was achieved if a Trombe wall was added to the building envelope.

The objective of this paper is to review the development on Trombe wall system for space heating and cooling. The academic research on Trombe wall is extensive, but this review is necessarily limited. Therefore, only the most pertinent scientific studies carried out in the recent 15 years is discussed in this review. Fig. 1 illustrates the journal papers distribution per year on the field of Trombe wall. We hope that the present information could provide a reference for architectural designers or related engineering designers.

## 2. Classification

Over time, modifications have been made to Trombe walls in order to improve their efficiency. Based on the major utilizing functions of Trombe walls, they are classified into two types: a heating-based type of Trombe wall and a cooling-based type of Trombe wall. Seven different configurations of heating-based types of Trombe wall will be described:

*Abbreviations:* HVAC, Heating, ventilation and air condition; SHW, Solar heating walls; CTW, Classic Trombe wall; TMW, Trombe–Michel wall; WTW, Water Trombe wall; ZTW, Zigzag Trombe wall; SCTW, Trombe wall in combination with solar chimney; HTF, Heat transfer fluid; LCA, Life cycle assessment; LCC, Life Cycle Cost; ACH, Air change per hour; PCM, Phase change material; FTW, Fluidized Trombe wall; PVTW, Photovoltaic Trombe wall; CECW, Ceramic evaporative cooing wall; HTF, Heat transfer fluid

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**Nomenclature**

| | |
|---|---|
| $Q$ | Heat gain (J) |
| α | The percentage of Trombe wall area to the total south wall area |
| $\eta$ | Thermal efficiency |
| $\dot{m}$ | Mass flow rate (Kg/s) |

(1) a classic Trombe wall (CTW); (2) a composite Trombe wall or Trombe–Michel wall (TMW); (3) a water Trombe wall (WTW); (4) a zigzag Trombe wall (ZTW); (5) a solar trans-wall (STW); (6) a fluidized Trombe wall (FTW); and (7) a photovoltaic Trombe wall (PVTW). Three different configurations of cooling-based types of Trombe wall will be introduced: (1) a ceramic evaporative cooing wall (CECW); (2) a classic Trombe wall and photovoltaic Trombe wall for cooling operation mode; and (3) a new designed Trombe wall in combination with solar chimney (SCTW). Fig. 2 illustrates the general classification. Each configuration of Trombe wall is discussed in detail in Sections 2.1 and 2.2, with their main advantages and disadvantages.

### 2.1. A heating-based type of Trombe wall

The concept of Trombe wall was patented by E.S. Morse in the 19th century and developed and popularized in 1957 by Félix Trombe and Jacques Michel. In 1967, in Odeillo, France, they built the first house using a Trombe wall. This wall is a simple configuration and designed to accumulate the solar heat and provide the interior space heating, which is known as classic or standard Trombe wall [10–12]. The exterior surface of the wall is colored black to increase the absorption rate and the surface of the classic Trombe wall is glazed. The channel is left between the wall and glass [13]. Fig. 3 shows the operating modes of a classic Trombe wall for winter heating.

The classic Trombe wall can catch solar radiation exploiting greenhouse effect created in a glazed cavity, and absorb and store heat using a massive wall. Part of the energy is transferred into the indoor of the building (the room) through the wall by conduction. Meanwhile, the lower temperature air enters the cavity from the room through the lower vent of the wall, heated up by the wall and flows upward due to buoyancy effect. The heated air then returns to the room through the upper vent of the wall. Whereby, heat exchange of Trombe wall with the indoor environment is partly by transmission through the wall and partly by ventilation through the vents. This simple configuration of Trombe wall suffer from the following shortcomings.

(1) Low thermal resistance. during the night or prolonged cloudy periods, some heat flux is transferred from the inside to the outside, which results in excessive heat loss from the building [11].
(2) Inverse thermo-siphon phenomena. when the storage wall is colder than the air in the ventilated layer, the air is cooled and re-injected into the room through the lower vent, particularly during the night in the cold season and hence decrease the room temperature [14].
(3) Low aesthetic value [15].

To increase the thermal resistance of the classic Trombe wall and control supplies, another heating-based type of Trombe wall, which is known as composite Trombe wall or Trombe–Michel wall [11,12], is developed. The composite Trombe wall consists of several different layers. These layers comprise a transparent outer cover, an enclosed air layer, a storage wall, a ventilated air layer, and finally an insulation layer (see Fig. 4). It works as follows. The first layer, which is transparent, dispatches the majority of the gained solar beams. Consequently, the storage wall absorbs part of the solar energy and heats up by greenhouse effect. The thermal energy can be transferred from outside to the interior air layer by conduction through the massive wall. Then it can be transferred by convection while using the thermo-circulation phenomenon of air between the massive wall and the insulating wall. In addition, a small portion of the energy is transmitted by conduction from the wall into the room. Therefore, nearly all the supply is provided to the building by means of the ventilated air layer. Due to greater thermal resistance of this design (the existence of the insulation layer and the air layers), there is little thermal flux that going from indoor to outdoor. Moreover, users can control the rate of heating at all times by adjusting the air circulation. While this type of Trombe wall can't avoid the reverse thermo-circulation of a classic Trombe wall and requires a mechanism to prevent it.

Another approach to reduce the heat loss of the classic Trombe wall is that using water for the heat storage instead of building materials, such as concrete, bricks, adobe, and stone. In this direction, the water Trombe wall is invented (see Fig. 5) [16,17]. Because the specific heat of water is higher than that of the building materials, the water's surface temperature does not rise as high as that of the masonry. Therefore, less heat is reflected back through the glazing. However, containing the water is much more difficult than containing solid materials such as masonry [18], which limited its spread.

Another heating-based type of Trombe wall is a zigzag Trombe wall, which is designed to reduce the excessive heating gain and also glare of sunny days [10]. As shown in Fig. 6, the wall consists of three sections. One section faces south. While the two other sections are angled inward forming a V-shaped wall. The section that faces southeast has a window that provides heat and light in the morning cold when immediate heating is required. Opposite the V shape is a classic Trombe wall, which stores heat for redistribution in the cold night hours.

Another innovative heating-based type of Trombe wall is a trans-wall (as shown in Fig. 7). It is a transparent modular wall that provides both heating and illumination of the dwelling space [19]. Therefore, a trans-wall plays an aesthetic role by providing visual access to a building's interior. These walls are comprised of water enclosed between two parallel glass panes supported in a metal frame. A semi-transparent absorbing plate is positioned between the parallel glass panes. The incident solar radiation is partially absorbed by the water and semi-transparent glass plate, the rest of the transmitted radiation

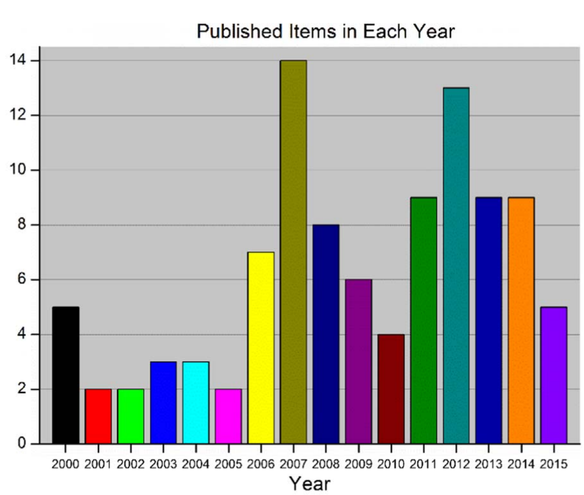


**Fig. 1.** Number of papers per year on the field of Trombe walls.

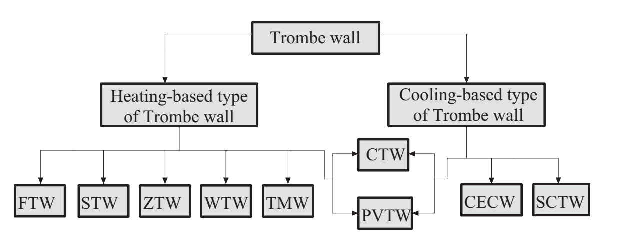


**Fig. 2.** Trombe wall classification.