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Study on the utilization of heat in the mechanically ventilated Trombe wall in a house with a central air conditioning and air circulation system

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HIGHLIGHTS

- A mechanically ventilated Trombe wall with additional windows in the storage wall was introduced.
- This Trombe wall was used for a house with a central air conditioning and air circulation system.
- The effective method of heat utilization of the Trombe wall was concluded.
- Airflow from the Trombe wall to the air conditioning room reduced the heating load.

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ABSTRACT

This paper presents a study on a mechanically ventilated Trombe wall that adds additional windows to the storage wall. The mechanically ventilated Trombe wall is located on the south side of the house with a central air conditioning and air circulation system. To reduce the heating load, during the heating period, the heat from the Trombe wall air channel is sent to the air conditioning room, from where it is then distributed and stored throughout the house by way of air circulation. Taking a house located in Miyazaki, Japan as an example, we conducted an actual survey to understand the situation of heat utilization of the Trombe wall and used numerical simulations to examine the effective method of heat utilization of the Trombe wall. Results showed that in all-day air conditioning, even when sending the air in the Trombe wall to the air-conditioned room, the temperature of the Trombe wall remained high. The heating load was reduced by sending the air from the Trombe wall to the central air-conditioned room and installing the large heat capacity material on the floor in the Trombe wall.

1. Introduction

Building energy consumption accounts for a great part of regional and global energy needs. Building energy consumption for cooling and heating accounts for 18–73% of overall energy consumption. Heating energy consumption occupies 32–33% of the overall building energy consumption [1]. Therefore, the use of renewable sources such as solar energy for building heating is an effective method. One of the easiest and cheapest methods of using solar energy is the Trombe wall, consisting of a transparent glazing panel, the air channel, the vent, and the storage wall [2]. Solar heat is stored by the storage wall during the day and released into the room at night. However, the traditional Trombe wall has several disadvantages such as low aesthetic value, changeable heat transfer, reverse thermo-siphon phenomena, and low thermal resistance [3].

Many scholars modified the traditional Trombe wall and found that the improved Trombe wall was more effective than the traditional Trombe wall. Rabani et al. [4] carried out an experimental analysis on the heating performance of an improved Trombe wall, which can obtain solar irradiance from the directions of south, west, and east. The results showed that the improved Trombe wall can increase the maximum temperature of absorbers 10 °C higher than the traditional Trombe wall. Yu et al. [5] presented a study on the formaldehyde degradation performance and heating performance of a TC-Trombe wall combining the

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Trombe wall with the thermal catalytic technology. The results indicated that the TC-Trombe wall can save the formaldehyde degradation energy and space heating energy up to 33.1 kWh/m^2 and 64.3 kWh/m^2, respectively. The zigzag Trombe wall [3] was invented to reduce glare and unnecessary heat increase, which comprises the southeast part, the southwest part, and the south part. The southeast part and southwest part form an inward "V"-shaped wall. The south part and southwest part are traditional Trombe walls; the southeast part is a window. Duan et al. [6] studied the thermal performances of two types of Trombe walls through a mathematical model, depending on the position of an absorber plate on the storage wall. They found that Trombe walls with absorber plates placed between the glass cover and the thermal storage wall are better than Trombe walls with the absorber plate pasted on the thermal storage wall. The particular exergy destruction, owing to absorption of the absorber plate is the largest and a higher absorber plate temperature is preferable in decreasing the total exergy destruction and increasing exergy efficiency. A non-ventilated Trombe wall with an additional window in the storage wall was proposed by Bellos et al. [7]. The results showed that the new non-ventilated Trombe wall can transfer the solar heat into the interior quickly, resulting in indoor temperature rising from noon to afternoon. Leang et al. [8] used the Dymola/Modelica software to study the energy performance of a composite Trombe wall. They compared a M_PCM (mortar phase change materials) composite Trombe Michel wall with a concrete composite Trombe Michel wall. The results showed that the M_PCM composite Trombe Michel wall has a great heat recovered capacity, which can recover 50% more energy than the concrete composite Trombe Michel wall. Hu et al. [9] carried out a study on the performance of three types of photovoltaic Trombe wall systems that can generate electricity and provide cooling/heating. Type 1 is photovoltaic blinds-integrated Trombe wall (PVBTW). Type 2 is photovoltaic cells attached to massive wall (PVMTW). Type 3 is photovoltaic cells attached to glass (PVGTW). The results showed that the type 1 (PVBTW system) can save 45% of the total electricity consumption and reduce the CO2 emission by 1.5 times compared with type 2 (PVMTW system) or type 3 (PVGTW system). Tunç and Uysal [10] conducted a numerical simulation study on the performance of the fluidized Trombe wall, in which the air cavity channel is fluidized by using low-density and highly absorbent particles. The results showed that fluidized Trombe walls gain more heat than traditional Trombe walls. Adams et al. [11] presented an experimental analysis on the performance of the water Trombe wall with three different water storage wall thickness levels (3 in., 6 in. and 9 in.). The results showed that the 9-in. and 6-in. water storage walls present better than the 3-in. water storage wall. The 3-in. storage wall did not adjust the temperature as well as the 9-in. and 6-in. water storage walls. The 9-in. and 6-in. water storage walls lagged a longer time than the 3-in. storage wall, which appeared to store and release the heat more efficiently. Sodha et al. [12] carried out a numerical study on the thermal performance of the solar transwall, which consists of a semi-transparent plate and glass walls. The results showed that the thermal performance of the solar transwall increases by increasing the water column thickness. Melero et al. [13] carried out an experimental study on the energy performance of a hybrid prototype Trombe wall integrated with a ceramic evaporative cooling system. They concluded that the hybrid prototype Trombe wall can improve the comfort of interior in summer and winter. Taffesse et al. [14] developed a mathematical model of SPVT-TW (semitransparent photovoltaic thermal Trombe wall) for the heating of a room by using the MATLAB R2013a software. They concluded that 0.4 m is the optimal thickness of the SPVT-TW for thermal load leveling.

There are various components to help improve the efficiency of the Trombe wall such as insulation, fans, shading devices, vents, glazing type, the storage wall's materials and thicknesses, coating materials, and air cavity depth. Ji et al. [15] proposed a numerical study on the thermal performance of the outer insulated Trombe wall. Results showed that the outer insulated Trombe wall performs more efficiently than the traditional Trombe wall, which can improve the operating efficiency of Trombe walls up to 56%. Ma et al. [16] used the software of THERB for HAM to study the thermal energy efficiency of a double-layer Trombe wall assisted by a fan. Results revealed that the double-layer Trombe wall assisted by the fan can increase the double-layer Trombe wall efficiency close to 5.6% and reduce heating demand by 0.6 kWh/m^3. Soussi et al. [17] studied the energy performance of the Trombe wall by using the TRNSYS software. Results showed that the total energy demand is reduced by using the movable solar overhangs, internal shading devices, and low-e Argon glazing. Briga-Sá et al. [18] studied the energy performance of the non-ventilated and ventilated Trombe wall with various thickness in the storage wall. Results showed that for the non-ventilated Trombe wall, the heat gains increased with the decreasing of the thickness of the massive wall. However, for the ventilated Trombe wall, the heat gains decreased when the thickness decreased. Liu et al. [19] carried out a numerical and experimental analysis on the closing and opening the air vent of the Trombe wall. They concluded that it is best to close the vent one hour before sunset and open the vent two hours or three hours after sunrise. Mohamed et al. [20] conducted a numerical simulation and experimental study on the performance of the Trombe wall in Tunisia. Results showed that in the periods of the highest solar radiation, the room temperature reaches 25 °C for the single glazed Trombe wall but does not exceed 22 °C for the double glazed Trombe wall. The single glazed Trombe wall allows a good transmission of energy and improves the comfort level of the interior. However, Stazi et al. [21] concluded that the Trombe wall performance increased with the use of double glazing and low-e single glazing in term of global warming potential. Rabani et al. [22] studied the heating duration of a room with various materials of the Trombe wall in periods of non-sunny days. Results indicated that the heating duration of a room with the paraffin wax wall was 8 h and 55 min, the salt wall was 8 h 30 min, the brick wall was 8 h 11 min, and the concrete wall was 7 h 12 min. Zhou and Pang [23] performed an experimental analysis of the thermal behavior of a PCM (CaCl2·6H2O) storage wall. The results showed that the surface temperature of PCM (CaCl2·6H2O) performs speedy–slow changes during the 17.5-hour discharging process and rises speedy–slow–speedy during the 6.5-hour charging process. Bojić et al. [24] studied the environmental and energy performance of Trombe walls that have various thickness of the storage wall. Results showed that for natural gas heating, the optimal thickness of clay bricks is around 0.25 m. For the electrical heating, the optimal thickness of clay bricks is around 0.35 m. Nwosu [25] conducted an analysis of the heat transmission balance of a Trombe wall. The results showed that the highly absorptive coating materials can improve the storage capacity of the Trombe wall. Burek and Habeb [26] conducted an experimental study on the mass flow rate and heat transfer in the Trombe wall. The results showed that the mass flow rate increases by increasing the heat input and air cavity depth. If the heat input is as high as 1000 W/m^2, the air cavity depth has no effect on the Trombe wall's efficiency.

Based on the author's review, the characteristics of the Trombe wall are summarized, including 12 different types of Trombe walls and various components that can help to improve the efficiency of Trombe walls. However, there is no study on the utilization of heat in the Trombe wall in a house with a central air conditioning and air circulation system. This paper presents a mechanically ventilated Trombe wall that adds additional windows to the storage wall. The use of additional windows can partly solve the Trombe wall's aesthetic problems and increase natural daylighting in the room. In addition, this configuration allows a portion of the solar radiation to heat the interior directly. The mechanically ventilated Trombe wall is located on the south side of the house with a central air conditioning and air circulation system. To reduce the heating load, during the heating period, the heat from the Trombe wall air channel is sent to the air conditioning room, from where it is then distributed and stored throughout the house by way of air circulation. The numerical calculations are done with the