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Experimental study of a modified solar phase change material storage wall system

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ABSTRACT

Aiming at satisfying demands of buildings in hot summer and cold winter regions, this work proposed a dual-channel and thermal-insulation-in-the-middle type solar phase change material storage wall system. The system has four independent functions: passive solar heating, heat preservation, heat insulation, and passive cooling, and it can agilely cope with requirements of climatization of buildings in different seasons throughout the year. The analysis of measured data from comparative tests on a hot-box test platform, shows that in summer, the daily average temperatures in the experimental room are 29.8 °C, 30.9 °C and 31.0 °C respectively, while those in the reference room are 29.6 °C, 30.7 °C and 30.8 °C, and thereby the difference is small. The south-facing wall with solar collector module shows reduction in peak temperature and delay phenomenon compared with that without solar collector module. These aspects highlighted by the results together indicate that effective prevention from summer overheating problem can be achieved by this system. In winter, by comparison with the ambient temperatures and those of the reference room, the air temperatures in the experimental room, both its maximum and average, raise greatly showing good heating effect. In addition, some distinct thermal characteristics of the system operated in summer or winter are obtained.

1. Introduction

Nowadays, the world is facing the deep adjustment of energy distribution to globally cope with the challenge of growing issues in climate change. The main cause of climate change issues is producing and consuming manner excessively relying on fossil energy resources, intrinsically an energy resource problem as well. According to the data of 2009 [1], 40% of fossil energy of EU and US is consumed in buildings. Solar energy is an important alternative to fossil resources, renewable and with environmental-friendly advantages. The efficient use of solar energy in buildings to reduce the final energy consumption of conventional energy by a significant percentage is an important approach to develop a low-carbon society. The way the phase change material (PCM) provides indirect heat storage is related to energy absorption, which turns into latent heat instead of self-temperature rise. Small volume, low temperature, and high heat storage are its strengths therefore PCM is a good and efficient heat storage material to be used in buildings climatization. Hence, the investigation of applying the combination of phase change material storage technology and solar energy utilization technology to energy efficient building emerges and receives more and more attention.

To date, composite PCM for energy efficient building has been deeply studied. Font et al. [2] investigated the performances of Polyol and its mixture and analyzed the prospect of getting their application in buildings. Hong and Xin-shi [3] investigated the structure and performance of shape-stabilized phase change material composed of paraffin and high-density polyethylene. In Ref. [4] the paraffin/expanded graphite composite PCM was prepared and its performance tested by X-ray diffraction, DSC, and scanning tunneling microscope (STM), and its faster phase change speed proved. Zhang et al. [5] prepared a novel heat-storage mortar by mixing conventional cement mortar and phase change material based on Octadecane and expanded Graphite, and experimentally proved its capability of reducing the energy consumption of buildings. Moreover, PCM's microencapsulation able to combine with building material more conveniently was investigated in Refs. [6–8].

Trombe wall, a heat-collecting system based on solar energy, is a high-efficiency simple structure that does not require maintenance.

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It combines solar energy utilization technology with conventional envelope structure of building; therefore, its broad application, improvement, and development have been implemented in the decades since it was proposed. By computational fluid dynamics (CFD) analysis based on experimental data, Koyunbaba et al. [9] proposed a BIPV Trombe wall model. The three-dimensional model for the shutter structure of Trombe wall was established in Ref. [10] and the comparison with experimental data and an optimal design scheme were conducted. With regard to the combination of solar energy application technology and PCM envelope structure, current researches and discussions mainly focus on PCM floor [11], PCM wall [12–15], and PCM roof [16,17].

Soares et al. [18] demonstrated that the approach of combining solar energy utilization technology and PCM envelope structure can effectively reduce the room temperature fluctuation in solar energy building caused by lack of solar energy during the night or uncertain weather, and thus enhancing the in-room thermal comfort. However, some large areas of China are characterized by hot summers, cold winters and usually require more than three months of air conditioning cooling. In winter, buildings need heating/heat preservation, while in summer they need heat cooling/insulation. Since solar energy is a thermal energy, it can be used conveniently for building heating in winter, but it can also cause overheating and heavy load of air conditioner in summer. Thus, in regions with hot summers and cold winters, current solar PCM storage technology cannot fully satisfy the application requirements.

Based upon the analysis above, this work proposes a novel solar PCM storage wall technology that combines Trombe-wall-like technology and phase change material storage technology, i.e. a dual-channel and thermal-insulation-in-the-middle type solar PCM storage wall (MSPCMW) system. This system has the following four independent functions: passive heating, heat preservation, heat insulation, and passive cooling. Therefore, it can easily cope with the requirements of different seasons throughout the year when applied to buildings in regions with hot summers and cold winters. By comparative tests conducted on hot-box test platform, the present work experimentally analyzed thermal characteristics of the proposed system and its influence on indoor thermal environment was investigated.

2. Principles of MSPCMW system and experiment introduction

MSPCMW system is based on a novel solar PCM storage wall technology with simple and compact structure, aiming at effective and reasonable use of solar energy in buildings located in regions with hot summers and cold winters. The system was installed on building's south-facing wall. Structural design of dual-channel and thermal insulation layer, appropriate design of vent opening switch, as well as the use of characteristics of PCM help achieving passive heating, heat preservation, heat insulation and cooling functions of buildings. A schematic of the system is shown in Fig. 1, mainly consisting of a MSPCMW module and a hot-box room with upper and lower vents. The module includes PCM wall, thermal insulation layer, interior and exterior flow channels, heat absorbing aluminum plate covered by selective absorption coating, indoor upper and lower vents, outdoor upper and lower vents, insulation layer upper and lower vents, glass cover board, and frame. The structure in which interior and exterior flow channels are separated by thermal insulation layer differs from the single-channel structure of conventional Trombe wall system. The detailed operation modes and functions are as follows:

Summer mode: (a) Heat insulation mode: in summer's daytime when building needs thermal insulation protection, indoor and middle layer upper and lower vents are closed, while outdoor ones keep open. Ambient wind pressure together with thermosiphon pressure would form a circular flow between exterior channels and outdoor air that takes the solar energy absorbed by aluminum plate back to environment. Meanwhile, thermal insulation layer prevents heat conduction into room, reducing building's absorption of solar energy. (b) Passive cooling mode: when needs insulation protection, such as summer's night, by taking advantage of relatively low air temperature in the night, indoor upper and lower vents shut while middle layer and outdoor ones keep open. Under the action of ambient wind pressure, the formed circular flow among interior channels, exterior channels and relatively cool air outdoors can cool down the PCM wall, reducing indoor temperature and storing PCM wall's cold energy.

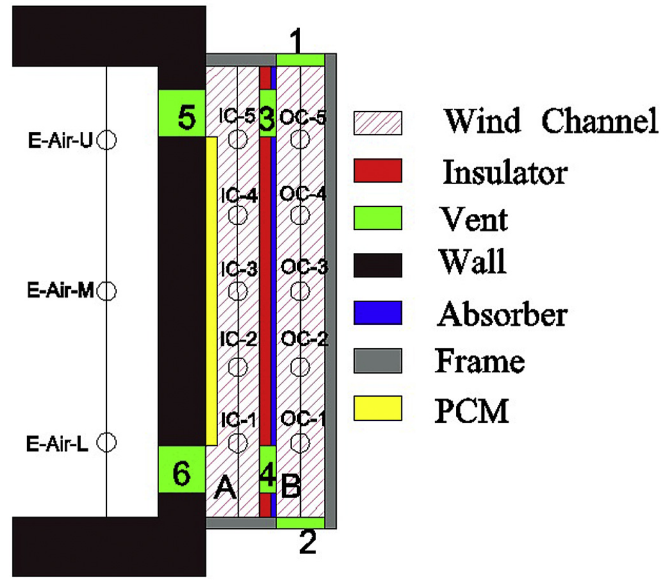

Fig. 1. The structural principle of the proposed system and the arrangement diagram of thermocouples.

Winter mode: (a) Solar passive heating function: in winter's daytime needing heating, the exterior upper and lower vents of system close, middle layer ones open, and interior ones can open/close to implement the interactive adjustment between the indoor temperature rise rate and the stored heat amount of PCM. Aluminum absorbing plate heats up the air of exterior flow channel by absorbing solar radiation irradiated on it. Among the air in the exterior channel, interior channel and indoor, the natural circulation due to thermosiphon occurs and induces circular exchange and heating up of PCM wall and indoor air, eventually achieving the solar passive heating in building. (b) Heat preservation function: in winter's nights needing heat preservation, the indoor, outdoor and middle layer upper and lower vents all close, and PCM wall transfers the heat stored during daytime into the room via heat conduction to the neighboring building wall. In addition, the thermal insulation layer composed of insulation material can block the heat loss toward outdoor as much as possible.

The experimental test of the system was carried out on a comparative hot-box test platform located in Hefei City, Anhui Province, characterized by hot summer and cold winter zone (Fig. 2). The test system included two hot-box rooms, proposed system module, vents, and an experimental parameter measurement system. The experimental room was the hot-box room installed with MSPCMW module, and the other one was the reference room. PCM wall was made by orderly laying and pasting 11 PCM plates on building's south-facing wall using thermal silicone grease. Each plate measured 0.45 m × 0.3 m × 0.01 m (L, W,