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Study on the coupling heating system of floor radiation and sunspace based on energy storage technology

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ABSTRACT

With the gradual increase of building energy consumption in recent years, the application of phase change energy storage materials in buildings has become the focus of researches. Phase change material (PCM) embedded in the envelope can increase the building inertia to keep the temperature stable. It can also store energy and release energy when needed. In this paper, the system of PCM radiant floor combined with PCM wall attached with sunspace was established. The thermal characteristics and the energy consumption of the building are studied through analyzing the data from the experimental investigation including the temperature and the heat flux. Two different buildings were built between the PCM room and the conventional room with the same dimension and building. The main test conditions are divided into passive and active control stages by comparing the air temperatures, envelope temperatures, phase transition temperatures, heat fluxes and power consumptions between the two rooms. It is concluded that the average room temperature of the experimental room is 7.15 °C higher than that of the conventional room in the passive energy storage stage. While the average energy-saving rate of PCM room was 54.27% compared with the conventional room in the active control stage.

1. Introduction

In recent years, the energy sector worldwide faces evidently significant challenges that everyday become even more acute [1]. There is not only the problem of energy shortage, but also the problem of energy pollution. The burning of fossil fuels is mainly responsible for global greenhouse gas emissions (GHGs). Oil accounts for 32.8%, coal for 27.2% and natural gas for 20.9% [2]. The excessive greenhouse emissions help climate change and cause environment issue worldwide. Human beings pursue higher quality of life, so the building energy consumption grows up, such as air-conditioning and hot water production energy. Building energy consumption in many countries has reached more than 35% of total energy consumption [3]. So, reducing energy consumption in the building sector is one of the most important measures for global energy reduction and climate adaptation [4].

The call for more sustainable energy usage patterns has grown substantially, and the terms "Sustainability" and "Green Building" have become concepts of widespread interest. The research and development of sustainability standards and rating systems became an international trend [5]. Renewable energy technologies applied in building field, mainly including solar energy and geothermal energy technologies, are recommended because of advances of energy efficiency, environmental protection and economic sustainability [6]. However, the supply of solar energy is influenced by the rotation of the earth and the weather, which is characterized by discontinuity and randomness. So, the thermal energy storage (TES) is expected to play a key role in taking advantage of solar radiation in buildings [7]. It is possible to provide power during no radiation periods such as nights or cloudy times of the day with TES system [8].

The sensible heat storage with temperature changed and the latent heat storage with phase changed are the main TES technologies [9]. Latent heat storage is one of the most efficient ways of storing thermal energy. Unlike the sensible heat storage method, the latent heat storage method provides much higher storage density, with a smaller temperature difference between storing and releasing heat [10]. Moreover, the latent heat storage technology PCMs such as sugar alcohols can potentially bridge the gap between peak heat demand and supply by storing energy in the form of latent heat due to their availability and suitable melting and freezing temperature ranges [11]. Due to the characteristics of PCMs, latent heat thermal energy storage with phase change materials owns countless potential in many applications, such as concentrated solar power, energy-efficient building and waste heat utilization [12]. Moreover, the use of PCMs heat is an efficient way

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to increase the thermal inertia of building envelopes, which would reduce temperature fluctuations, leading to the improved thermal comfort of occupants [13,14]. There are two types of PCM-based TES systems that can be used in buildings: active and passive storage systems. Active systems require an additional fluid loop to charge and discharge a storage tank. On the contrary, passive systems don't require such heat exchanger to extract heat or cold from the storage [15].

Lightweight envelopes (used primarily for economic reasons) are widely used in modern buildings but their low thermal capacity does not allow an optimal thermal comfort situation [16]. The PCMs commonly incorporated in the envelope of the building to solve this problem. Floor [17], wall [18], roof [19] and window [20] are the main locations that the PCMs are embedded in. And the PCMs always integrate with solar energy system and electrical heating system to reduce energy consumption. The PCMs absorb solar radiation during daytime and release the heat at night. And use the differential power prices to charge the PCMs at low price and PCMs provide energy at high price [21,22].

It must be noted that PCMs encapsulation is difficult to master. The PCMs can be incorporated in buildings by direct incorporation, encapsulation and form stable-composite. Due to the PCMs absorbed heat with phase change, the direct incorporation is at risk of leakage [23]. In order to avoid this problem, the encapsulation PCMs are commonly used. Microencapsulated PCMs and macro-encapsulated PCMs are the two types of encapsulation. The encapsulation can avoid the leakage of the PCMs, but it makes the poor thermal conductivity [24,25]. The form stable-composite PCMs is developed in recent years. It can avoid the PCMs leakage during the cyclic process and the thermal conductivity is high [26].

A few studies dealt with the effect of using PCM on the thermal performance of the solar energy storage. Kabeel et al. [27] integrated solar air heater with paraffin. it was found that when using the PCM, the outlet temperature of the v-corrugated plate solar air heater was higher than ambient temperature by 1.5–7.2 °C during 3.5 h after sunset compared with 1–5.5 °C during 2.5 h after sunset for flat plate solar air heater when the mass flow rate was 0.062 kg/s. Shuhong Li et al. [28] incorporated PCM into triple-pane window (TW). The results show that compared with double-pane window (DW) with PCM and TW, the peak temperature on the interior surface of TW + PCM reduces by 2.7 °C and 5.5 °C, which means the overheating risk is avoided effectively, and heat entered the building through the TW + PCM reduces by 16.6% and 28% respectively in the sunny summer day. Guarino et al. [7] embedded PCMs in the wall opposing a highly-glazed façade (south oriented). The concept considered is particularly suited to retrofits in a solarium since the PCM can be added as layers facing the large window on the vertical wall directly opposite. Results show that the thermal storage allows solar radiation to be stored and released up to 6–8 h after solar irradiation which has effects on both the reduction of daily temperature swings (up to 10 °C) and heating requirements (more than 17% on a yearly base). Álvarez et al. [29] placed the PCM in the core of mechanically ventilated air layers which allows a significant increase of the convective heat transfer coefficients and improved the utilization factor due to the inclusion of active control systems which allow the cold stored be actually used when required.

These studies provide a valuable reference for this article. There are a lot of studies on the heating performance of PCM floor and the PCM wall. However, it is lack of studies on the heating performance of PCM floor combined with PCM wall. And it is also lack of studies on the energy-saving performance of the combination of the two methods. So, in this paper a test-bed with PCM floor combined with PCM wall attached with sunspace was set up. The PCM panel incorporated with fluid loop can absorb energy actively. When the water in the fluid loop is heated by solar water heater or electric heater, the energy can store in the PCM with circulation. The sunspace with completely transparent glass frame can allows the solar radiation to pass in, and it can also reduce the heat loss. In this paper, the thermal performance of the PCM floor radiation heating system coupled with PCM wall attached with sunspace is experimentally tested.

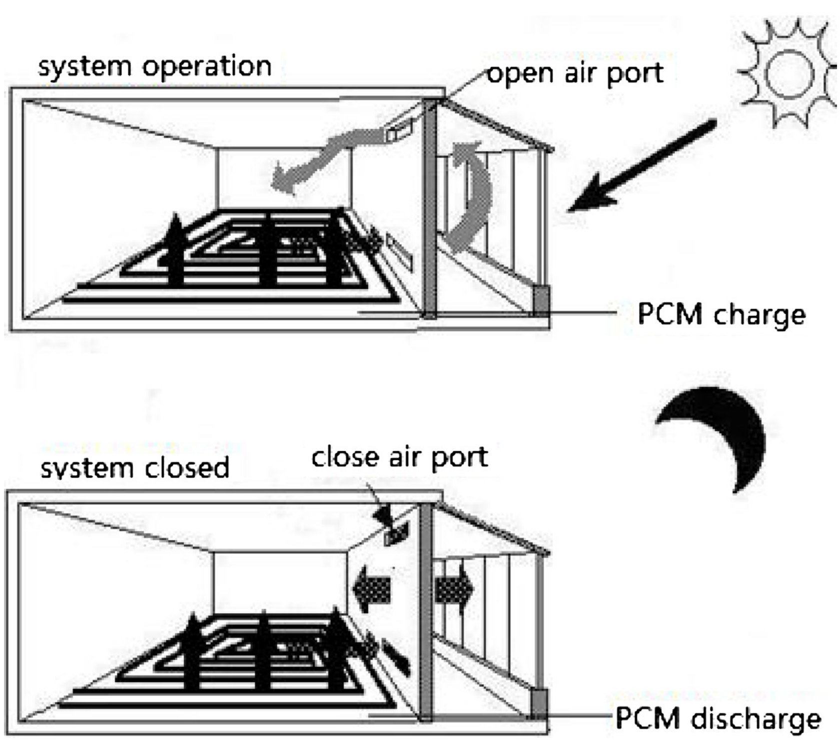

Fig. 1. Operating principle of the system.