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Research Paper

Diurnal performance analysis of phase change material walls

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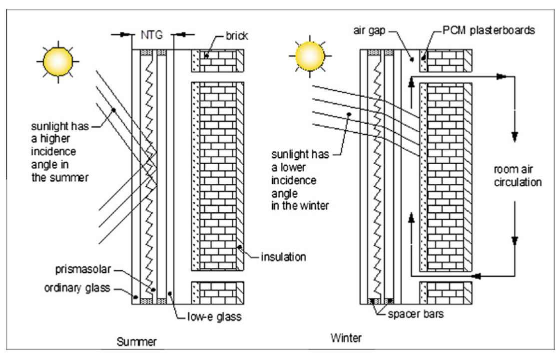
HIGHLIGHTS

- The novel triple glass prevents the PCM wall from overheating in the summer.
- The PCM walls provide 17% of the heat load on a sunny day in the heating period.
- The average daily overall efficiency of PCM walls is 19% in the heating period.

GRAPHICAL ABSTRACT



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ABSTRACT

A research study was conducted to investigate the thermal performance of phase change material (PCM) walls. The south-facing external wall of a test room was constructed using PCM walls composed of brick walls, plasterboards containing PCMs, and novel triple glass. The thermal performance of the PCM walls was experimentally determined on a daily basis. The ratio of the solar energy gain provided by the PCM walls to the heat load of the test room on a daily basis varied from 12% to 25%; daily overall efficiency of the coupled novel triple glass and PCM walls varied from 17% to 20%; and solar transmittance of the novel triple glass varied from 45% to 55% during the heating period.

1. Introduction

Latent heat storage in phase change materials (PCMs) is an efficient way to store thermal energy because PCMs have a high-energy storage density over a narrow temperature range. Solar energy can be absorbed and stored in the building envelope by incorporating PCMs into the walls, ceilings, floors, and windows of the building.

The following related topics have been reviewed and discussed by different researchers: the basic principles of storing solar energy by incorporating PCMs into building envelopes; the thermophysical properties of candidate PCMs for building applications; the methods of PCM encapsulation; the methods of PCM incorporation into building envelopes; thermal analyses of PCM-enhanced walls, ceilings, and floors; the effect of PCM inclusion in the building envelope on the thermal performance of the building; and manufacturing methods for producing PCM-enhanced wallboards, concrete, and building insulation materials [1–8].

Chan [9] developed a theoretical model to investigate the thermal performance of a flat with PCM-incorporated external walls. It was reported that the external PCM walls provided energy savings of 2.9% by reducing the need to use the air conditioning system in the flat. Diaconu and Cruceru [10] proposed a three-layer composite wall system. The external and internal layers of the composite wall were PCM wallboards impregnated with different PCMs, and the middle layer was a thermal insulation panel. The melting point of the PCM in the external layer was higher than that in

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Nomenclature

A	area (m^2)
c_p	specific heat (W/kg K)
E	energy (J)
I	solar irradiation (W/m^2)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat rate (W)
t	time (s)
T	temperature (K)
η	efficiency
ρ	density (kg/m^3)

Subscripts

c	cross-section
d	daily
g	gain
h	heat load
lv	lower vent
i	incident
o	overall
s	surface
t	transmitted
uv	upper vent

Abbreviations

NTG	novel triple glass
PCM	phase change material
RSEG	ratio of solar energy gain
SEG	solar energy gain
ST	solar transmittance
HVAC	heating ventilating and air-conditioning

the internal layer. An annual simulation for a room constructed with a composite wall system was carried out, and it was found that the composite wall system reduced the peak value of cooling/heating loads of the room and provided energy saving. Zhang et al. [11] developed a model based on an enthalpy-porosity technique to investigate the thermal response of brick walls filled with PCM. They found that the use of PCM in brick walls was beneficial for thermal insulation, temperature hysteresis, and thermal comfort. Xiao et al. [12] calculated the optimal phase change temperature and the total amount of latent heat capacity to estimate the benefit of the interior PCM for energy storage in a lightweight passive solar room by solving analytical equations.

Kuznik and Virgone [13] investigated the thermal performance of a test room with PCM copolymer composite wallboards. They found that the PCM wallboards reduced the air temperature in the room up to 4.2 °C during the summer time. Kuznik et al. [14] investigated the thermal performance of PCM wallboards by monitoring two identical rooms. One of the rooms had PCM wallboards placed on the internal surfaces of the walls and the ceiling. Comparing the indoor air temperatures and the wall surface temperatures of the rooms, they inferred that PCM wallboards enhanced the thermal comfort of occupants. Cerón et al. [15] developed and designed a new prototype of tile including PCM. The PCM tiles consisted of clay stoneware, a top metal sheet, a metal container containing the PCM, and a thermal insulation layer. They placed the PCM tiles on the floor of the test room receiving solar radiation. They found that during the day, the surface temperature of the PCM tiles was slightly higher (1–2 °C) than that of tiles without PCM. They concluded that the PCM tiles placed on the floor decreased heat loss through the floor during the winter and could be used as passive thermal conditioners in a house to stabilise the room temperature.

Liu and Awbi [16] tested the thermal performance of a test room with PCM wallboards under natural convection. They placed the PCM wallboards on the inner surface of the room's wall. They found that PCM wallboards reduced the heat flux density and the interior wall surface temperature during the charging process, and the heat insulation performance of the PCM wall was better than that of an ordinary wall. Castellón et al. [17] investigated the thermal performance of sandwich panels including microencapsulated PCM. They added the microencapsulated PCM to the sandwich panels in order to increase their thermal inertia.

Cabeza et al. [18] built two identical concrete cubicles as test rooms; one was constructed using PCM-enhanced concrete, and the other was constructed using conventional concrete without PCM. A commercial microencapsulated PCM with a melting point of 26 °C was used in the concrete. The results of the study showed that the PCM-enhanced concrete cubicle had a better thermal mass and a lower inner temperature compared with the conventional concrete cubicle. Castell et al. [19] constructed several test chambers using two types of brick walls integrated with PCM and an identical reference chamber without PCM to compare the chambers' thermal performance under real conditions. They monitored the temperature of the walls, the indoor air temperature of the chambers, and the heat flux entering through the south wall. They performed the tests both with and without an air conditioner. They found that the PCM could reduce the peak temperatures up to 1 °C and smooth temperature fluctuations. Furthermore, a 15% energy savings was achieved in the PCM chambers. Menoufi et al. [20], Castell et al. [21], and Gracia et al. [22] performed life cycle assessment for the most sustainable building construction by testing several experimental cubicles with the different building, insulation, and phase change materials.

A shape-stabilised PCM is a compound material made of PCMs and supporting materials (usually high-density polyethylene). The shape-stabilised PCM keeps its form unchanged during the phase change process. The preparation methods and thermophysical properties of shape-stabilised PCMs were given by Zhang et al. [23]. Some of the applications of shape-stabilised PCM panels in buildings were studied both experimentally and numerically by different researchers [24–28]. More than half of the total electricity consumption of a room can be shifted from the peak period to the off-peak period by combining an under-floor electrical heating system with shape-stabilised PCM panels [24,25]. The shape-stabilised PCM plates improve indoor thermal comfort by decreasing the daily maximum temperature by up to 2 °C due to the cool storage at night and eliminate approximately 47% of normal and peak-hour energy use, and decrease 12% of energy consumption in winter when they are placed on the interior surface of the walls and the ceiling of a room as inner linings [26–28].

Gracia et al. [29] tested experimentally the thermal performance of a ventilated double skin façade with phase change material in its air channel, during the heating season in the Mediterranean climate. Two identical house-like cubicles were monitored during winter, and in one of them, a ventilated facade with PCM was located in the south wall. This ventilated facade can operate under mechanical or natural ventilation mode and its thermal control depends on the weather conditions and the