# Modeling and simulation on the thermal performance of shape-stabilized phase change material floor used in passive solar buildings

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## Abstract

Shape-stabilized phase change material (PCM) is a kind of novel PCM. It has the following salient features: large apparent specific heat for phase change temperature region, suitable thermal conductivity, no container. In the present paper, a kind of shape-stabilized PCM floor is put forward which can absorb the solar radiation energy in the daytime and release the heat at night in winter. Therefore, in winter the indoor climate can be improved and the energy consumption for space heating may be greatly reduced. A model of analyzing the thermal performance of this shape-stabilized PCM floor is developed. By using the modeling, the influence of various factors (thickness of PCM layer, melting temperature, heat of fusion, thermal conductivity of PCM, etc.) on the room thermal performance was analyzed. The model was verified by the experimental results. The model and the analysis are helpful for the application of shape-stabilized PCM floor in solar buildings.
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## 1. Introduction

Solar radiation is a time-dependent energy source with an intermittent character and the peak solar radiation occurs near noon. Thermal energy storage can provide a reservoir of energy to adapt the changes of solar energy [1]. Energy storage in the walls, ceiling and floor of buildings may be enhanced by impregnating some suitable PCM in them. PCM can absorb solar energy at daytime while PCM changes from solid to liquid, and releases the energy and freezes back to solid when the room temperature falls down at evening [2]. Therefore, the human comfort level can be increased by using PCM to lower indoor air temperature fluctuation and maintain the indoor air temperature to the desired range for a longer period. Phase change materials can provide large latent heat storage over the narrow range of temperature typically encountered in buildings, thus they can improve the thermal comfort degree [3].

Shape-stabilized PCM is a kind of novel PCM being composed of macromolecule material as the supporting material and paraffin as a dispersed PCM. Because the paraffin is micro-encapsulated in the supporting material, the compound can keep its shape stabilized when paraffin undergoes phase change. Therefore, containers are not necessary in application. Compared with conventional PCM, shape-stabilized PCM reduces the liquid PCM leakage danger, the additive thermal resistance and container cost. This material can be shaped into plates or added into concrete to be directly applied as floor or wallboard. In recent years, some researchers have studied the preparing method and the thermal properties of several shape-stabilized PCMs [4–6].

We developed a new kind of shape-stabilized PCM plate, which consists of 70 wt.% paraffin as the dispersed PCM and 15 wt.% polyethylene and 15 wt.% styrene–butadiene–styrene (SBS) block copolymer as the supporting materials.

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## Nomenclature

| | |
|---|---|
| $A$ | area (m$^2$) |
| ACH | air change per hour (1/h) |
| $c_p$ | specific heat (kJ/(kg K)) |
| $g$ | gravity acceleration (9.8 m/s$^2$) |
| $Gr$ | Grashof number |
| $h$ | convective heat transfer coefficient (W/(m$^2$ K)) |
| $H$ | enthalpy (kJ/kg) |
| $H_m$ | heat of fusion (kJ/kg) |
| $k$ | thermal conductivity (W/(m K)) |
| $L$ | thickness (mm) |
| $Nu$ | Nusselt number |
| $Pr$ | Prandtl number |
| $q$ | heat flux (W/m$^2$) |
| $Q$ | heat transfer rate (W) |
| $T$ | temperature (°C) |
| $U$ | overall heat transfer coefficient (W/(m$^2$ K)) |
| $V$ | cubage (m$^3$) |

### Greek symbols

| | |
|---|---|
| $\alpha$ | air coefficient of volume expansion (1/K) |
| $\rho$ | density (kg/m$^3$) |
| $\tau$ | time (s) |
| $V$ | air viscosity (m/s$^2$) |

### Subscripts

| | |
|---|---|
| a | air |
| f | floor |
| gap | air-gap |
| in | indoor |
| init | initial |
| l | liquid state of PCM |
| leak | air leak from room |
| m | phase transition state of PCM |
| out | outdoor |
| PCM | phase change material |
| r | radiation |
| R | room |
| s | solid state of PCM |
| w | wall |
| w, s | wall surface |
| win | window |

We studied a kind of under-floor electric heating system with such shape-stabilized PCM plates and analyzed its thermal performance [7,8].

A kind of shape-stabilized PCM floor used in passive solar buildings was put forward and investigated experimentally in our previous paper [9]. However, it is impossible to study the thermal performance of various buildings located in different regions only through experiments conducted in a test house. And it is difficult to know clearly the influences of various factors on the thermal performance of such floor systems without modeling and simulation. All of those are very important to properly apply such systems in passive solar buildings. Thus, apart from experiments, modeling and simulation are necessary. Certainly, they should be validated with experiments.

Farid and Kong applied one-dimensional heat conduction equation to describe heat transfer in both the concrete and the concrete-PCM layers. They assumed that the specific heat capacity of PCM was in proportion to temperature during melting or freezing [10].

Enthalpy model is simpler in phase change calculation. It takes enthalpy as the only variable instead of temperature and specific heat capacity. Shamsundar and Sparrow proved the equivalence of the mathematical representation of the enthalpy model and the conventional heat conduction equations in the solid and liquid regions and at the solid-liquid interface [11]. Therefore, enthalpy model is applied in this paper.

The objectives of this work are: (1) to develop a model of analyzing the thermal performance of the shape-stabilized PCM floor; (2) to study the influences of various factors on the thermal performance of the system; (3) to study the feasibility of applying such system in different climate regions of China; and (4) to provide a simulation tool for designing such system.

## 2. Heat transfer analysis

In order to simplify the analysis, the following assumptions are made: (1) heat transfer through walls, floor and ceiling is one-dimensional; (2) thermal physical properties of the building materials are constant except the specific heat of PCM during melting or freezing process; (3) the shape-stabilized PCM plate under surface is thermally insulated.

### 2.1. Heat transfer model of the shape-stabilized PCM floor

The shape-stabilized PCM floor is shown in Fig. 1.

Based upon the above assumptions, the transient heat transfer equation of the floor is:

$$\rho_f c_{p,f} \frac{\partial T(x,\tau)}{\partial \tau} = k_f \frac{\partial^2 T(x,\tau)}{\partial x^2} \tag{1}$$
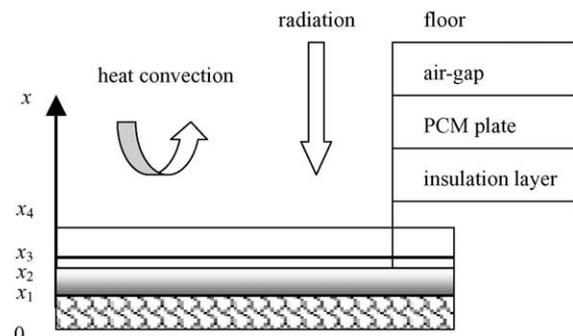


Fig. 1. Schematic of the shape-stabilized PCM floor.