Energy and Buildings 67 (2013) 508–516

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# A simplified dynamic model of double layers shape-stabilized phase change materials wallboards

Na Zhu*, Pingfang Hu, Linghong Xu

*Department of Building Environment and Equipment Engineering, School of Environment of Science and Engineering, Huazhong University of Science and Technology, Wuhan, Hubei 430074, PR China*

ARTICLE INFO

*Article history:*
Received 12 July 2013
Received in revised form 20 August 2013
Accepted 23 August 2013

*Keywords:*
Simplified model
Shape-stabilized phase change material
Double layers
Parameters identification
Genetic algorithm

ABSTRACT

A simplified dynamic building model was proposed and validated in this study. The structure of the new wall system is that of a three-layer sandwich-type panel with outer layers consisting of SSPCM wallboards and middle layer consisting of conventional brick. Each layers of the composite wall have different functions: the external layer connected to outside has a higher PCM melting temperature used in summer and the internal layer connected to indoor with a PCM melting temperature near indoor set point used in winter. The middle layer is brick for insulation. Few studies have involved simplified dynamic models of building structures integrated with double layers SSPCMs. The simplified dynamic model represents the brick layer by three resistances and two capacitances (3R2C) and the SSPCM layer by four resistances and two capacitances (4R2C) while the key issue is the parameters identification of the model. The parameters of the simplified model are identified using genetic algorithm (GA) on the basis of the basic physical properties of the brick and SSPCM layer. Validation results show that the simplified dynamic model can represent light weight walls and median weight walls integrated with double layers SSPCMs with good accuracy.



## 1. Introduction

Latent heat storage in a phase change material (PCM) is very attractive because of its high-energy storage density and its isothermal behavior during the phase change process. A substantial amount of studies is available on the applications of PCMs in buildings to enhance their thermal and energy performance. In recent years, the shape-stabilized PCM has been attracting the interests of the researchers. The SSPCM consists of PCM as dispersed phase and high-density polyethylene or other materials as supporting material. The mass percentage of PCM contained can be as much as 80% or so and the compound material keeps its shape as long as the operating temperature is below the melting point of the supporting material. This reduces the liquid PCM leakage danger and it can be used for thermal storage in buildings without encapsulation. The integration of SSPCMs into construction elements to enhance the energy efficiency of buildings has been studied by many authors [1–23]. Zhou et al. [11] numerically investigated the thermal performance of a hybrid space-cooling system with night ventilation and thermal storage using SSPCM. A south-facing room of an office building in Beijing is analyzed, and the electrical COPs of night ventilation (the reduced cooling energy divided by fan power) are 7.5 and 6.5 for cases with and without SSPCM, respectively. The hybrid system could improve the indoor thermal comfort level and save 76% of daytime cooling energy consumption in summer in Beijing (compared with the case without SSPCM and night ventilation).

Only a few studies have been performed on double layers PCM integrated into constructions for year-round application. Pasupathy et al. [22] studied the thermal performance of an inorganic eutectic PCM based thermal storage system for thermal management in a residential building with mathematical models. The system has been analyzed by theoretical and experimental investigation. A double layers PCM concept is studied in detail to achieve year round thermal management in a passive manner. Diaconu et al. [23] proposed a new type of composite wall system incorporating phase change materials (PCMs) and its potential for cooling/heating energy savings in continental temperate climate was evaluated. A year-round simulation of a room built using the new wall system was carried out and the effect of PCM presence into the structure of the wall system was assessed in this study. It was found that the new wall system contributes to annual energy savings (1% energy saved in summer and 12.8% energy saved in winter) and reduces the peak value (35.4%) of the air-conditioning/heating loads.

In the studies available in the literature, most of the systems [1–21] are numerically or experimentally studied for extreme cold or hot conditions and few studies are carried out for spring or autumn conditions. Typically, passive systems are also optimized to solve only either the winter or the summer problem and a few

* Corresponding author. Tel.: +86 027 87792164x415.
*E-mail address:* bezhuna@163.com (N. Zhu).

0378-7788/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.08.043

**Nomenclature**

| | |
|---|---|
| $C$ | capacitance (kJ/K) |
| $C_p$ | specific heat (kJ/kg K) |
| $D$ | thickness of materials (mm) |
| $f$ | fitness function |
| $h$ | convective heat transfer coefficient (W/m$^2$ K) |
| $H$ | enthalpy (kJ/kg) |
| $k$ | thermal conductivity (W/m K) |
| $N$ | the number of frequency points |
| PL | phase lag (rad) |
| $Q$ | cooling/heating load or heat (kW) |
| $R$ | resistance (K k/W) |
| SSPCM | shape-stabilized phase change material |
| $T$ | temperature (°C or K) |
| $J$ | objective function |
| $W$ | weighting factor |

*Greek symbols*

| | |
|---|---|
| $\alpha_i$ | $i$-th element of coefficient vector |
| $\beta_i$ | $i$-th element of coefficient vector |
| $\rho$ | density (kg/m$^3$) |
| $\omega$ | frequency (rad/s) |

*Subscripts*

| | |
|---|---|
| a | air |
| ex | external or outdoor |
| in | internal or indoor |
| p | phase change material (pcm) |
| sol | solar |
| s | simplified model |
| t | theoretical model |
| w | wall |

studies [22,23] are carried out about their performances in year-round application. Some building envelopes integrated with one-layer PCM do not agree with the real life building construction where more layers of other materials may be necessary because of architectural, esthetic, regulatory or structural purposes. Hence, many layers of other materials (e.g. a mortar, a brick, a concrete or any other layer enhanced with PCMs) should be considered as a part of a passive system, and the system must be optimized as a whole. The most promising passive latent heat thermal energy storage systems with PCMs to be developed for building applications are those related with harnessing solar thermal energy for heating during winter and those optimized to reduce the overheating problem during summer [24]. Almeida et al. [25] evaluated the potential of using multiple layers of PCM versus using a single PCM layer. It was found that the application of PCMs can significantly affect the thermal performance of the building, and it was shown that multilayered PCM demonstrated more thermal benefit than single PCM layer.

The accurate prediction of the dynamic characteristics and energy performance of buildings using PCMs is essential, which can help building practitioners to fully understand the building temperature response characteristics and potential energy savings due to the use of PCMs. They can therefore properly select and design the building and the use of PCMs and properly control the system to fully use the energy saving potential provided by the PCMs.

In order to predict the overall energy consumption, it is essential to have models to estimate the cooling/heating energy consumption needed for maintaining the air temperature and humidity in buildings. Over the last two or more decades, there were many mathematical models to analyze the thermal performance of building integrated with PCMs [26–32]. These mathematical models were mainly on the basis of first law and second law of thermodynamics. Zhang et al. [26] presented a general model which can be used to analyze the instantaneous temperature distribution, instantaneous heat transfer rate, and thermal storage capacity of a LHTES system. Halford et al. [27] developed an idealized model for PCMs. This model uses the one-dimensional diffusion equation driven by time varying temperature functions imposed at the boundaries. Heim et al. [28] presented a numerical model for PCMs encapsulated in porous building materials. Vakilaltojjar et al. [29] presented a semi-analytical model for PCMs using the finite elements method. A heat transfer model of SSPCM wall and ceiling was presented by Zhou et al. [30]. Although these mathematical models can well describe the heat transfer processes of building envelopes integrated with PCMs, they were too complicated to apply in many practical applications concerning computation speed and program size particularly when involving large buildings or models are used for online applications.

In author's previous study [7], the SSPCM plate as inner linings of wall was active during summer. The paper presented a simplified dynamic model for building structure integrated with one-layer SSPCM, and particularly a method to identify the parameters of the model, including the brick layer (3R2C model) and the SSPCM layer (4R2C model). The simplified building model can well represent thermodynamic performance of the building envelopes integrated with SSPCM for walls of normal thickness (not more than 300 mm approximately) including light weight wall and median weight wall.

This study presents a method to simplify building model integrated with double layers SSPCMs and identify their parameters using easily available building physical properties based on the previous research. The external layer and the internal layer are SSPCM plates and simplified by two 4R2C models. Middle layer is conventional brick and simplified by a 3R2C model. The parameters are identified by GA estimators to find the best matching of the frequency response characteristics between the simplified model and the theoretical model of wall.

## 2. Description on simplified model

A simple chamber is considered as the ideal model house for double layers SSPCMs wall model validation, which has only one exterior wall integrated with double layers SSPCMs (the south wall), as shown in Fig. 1. The dimension of the room is 5.0 m (length) × 4.0 m (width) × 3.0 m (height). The external layer connected to outside is active in summer and the internal layer connected to indoor is active in winter. For the simplicity and reliability of validation, the other three walls, ceiling and floor are considered to be thermally isolated while the indoor air is considered to be

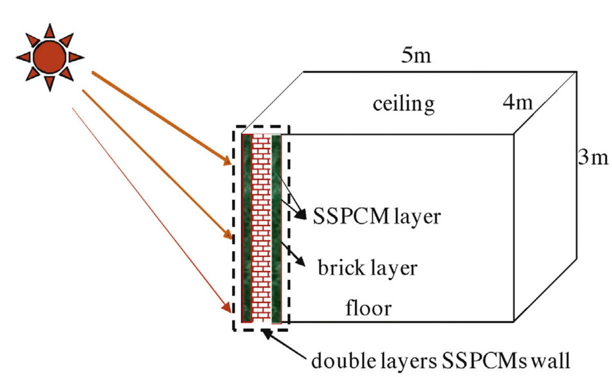


**Fig. 1.** Schematic of double layers SSPCM wall.