Energy and Buildings 152 (2017) 547–557

Contents lists available at ScienceDirect

Energy and Buildings

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

Development and thermal performance of an expanded perlite-based phase change material wallboard for passive cooling in building

Xiangfei Kong[a], Chengqiang Yao[a], Pengfei Jie[b,*], Yun Liu[a], Chengying Qi[a], Xian Rong[c]

[a] School of Energy and Environmental Engineering, Hebei University of Technology, Tianjin 300401, China
[b] School of Mechanical Engineering, Beijing Institute of Petrochemical Technology, Beijing 102617, China
[c] School of Civil and Transportation Engineering, Hebei University of Technology, Tianjin 300401, China

ARTICLE INFO

Article history:
Received 10 March 2017
Received in revised form 14 May 2017
Accepted 27 June 2017

Keywords:
Phase change material
Paraffin
Expanded perlite
Thermal performance
Thermal storage

ABSTRACT

Phase change material (PCM) used in buildings can enhance indoor thermal comfort and decrease building energy consumption. A kind of shape-stabilised PCM particle (PCMP) was prepared by liquid paraffin to be absorbed into the micropores of expanded perlite (EP) with a self-made vacuum heating rolling box. A novel composite phase change material wallboard (CPCMW) was fabricated by PCMP, styrene acrylic emulsion and glass fibers under a plate-shape mould. The properties including thermal property, internal microstructure and mechanical property have been characterized by differential scanning calorimeter(DSC), scanning electron microscope (SEM) and electronic universal testing machine. The cold storage performance of CPCMW was experimentally studied in two rooms with the same size, under the summer condition. CPCMW was incorporated with the inside surface of wall and ceiling in a room, which was called PCM room (PCMR); while the other one without PCM was addressed as reference room. Besides, three operation strategies, i.e. natural convection operation with time(NCTI), natural convection operation with temperature (NCTE), and cold storage in closed building were conducted in experiments. In DSC test, the melting point and latent heat of CPCMW were 25.22 °C and 85.63 J/g, respectively. From SEM and electronic universal testing machine analyses, it was found that CPCMW had a compact and firm microstructure, and good strength and toughness. Based on the comparison data of PCMR and reference room in the experiment of cold storage, CPCMW showed a satisfied thermal performance, especially with the operation strategy of NCTE. It can be concluded that the novel CPCMW has a significant opportunity for building application.

1. Introduction

Building energy consumption decreasing and indoor thermal comfort enhancing are important research areas in building technology. The commonly used insulation material, such as the polystyrene board, only increases the thermal resistance of building envelope, but it cannot increase the thermal storage capacity and adjust the indoor temperature. As a kind of passive building energy-efficiency technology, PCM used in building envelope can enhance building thermal inertia, because of the large latent heat of PCM [1,2]. When the external temperature is higher than the melting point, PCM starts to absorb heat from surrounding environment due to its change from solid phase to liquid phase; on the contrary, if the external temperature is lower than the freezing point, PCM can release the heat back to the surrounding environment during the solidification process [3,4]. The temperature in the phase change process can maintain within a smaller and roughly constant range, so PCM can decrease the temperature change range of inside building. Besides, the heat storage capacity of PCM is larger than the ordinary building insulation material. Thus PCM can enhance the heat capacity of building envelope with no large quality increasing, especially in lightweight buildings [5].

The studies about PCM applications in buildings mainly include PCM wallboard [6–8], PCM wall [9,10], PCM floor [11,12] and ceiling [13,14], and PCM shutter [15]. For the high thermal storage capacity, PCM wallboard can be used in building with relatively low mass; meanwhile, because of its plate shape, it needs little or no additional space and can be flexibly applied in both new and rehabilitated buildings [16]. The current method for PCM wallboard fabrication can be summed up as three aspects: macroencapsulation [17–19], microencapsulation [20,21] and shape-stabilised PCMs [22–24]. The shape-stabilised PCM can be prepared from the

* Corresponding author.
E-mail addresses: xfkong@hebut.edu.cn (X. Kong), pengfeijie@163.com (P. Jie).

http://dx.doi.org/10.1016/j.enbuild.2017.06.067
0378-7788/

Nomenclature

T	Temperature (°C)
I	Solar radiation intensity (W/m^2)
α	Solar radiation absorption coefficient (W/(m^2 °C))
PCM	Phase change material
PCMP	Phase change material particle
PCMR	Phase change material room
CPCMW	Composite phase change material wallboard
EP	Expanded perlite
EPS	Expanded polystyrene board
DSC	Differential scanning calorimeter
SEM	Scanning electron microscope
BCSSIB	Blue colored steel sandwich insulation board
IFB	Insulation foam boards
NCTI	Natural convection operation with time
NCTE	Natural convection operation with temperature

Subscripts

air	Outdoor air
out	Outside surface

mixing method, in which a kind or several kinds of liquid PCMs can be mixed with a supporting material, such as high-density polyethylene, expanded perlite, expanded vermiculite, etc. [25,26]. Due to the simple preparing process, large heat storage capacity during phase change period, suitable thermal conductivity, fixed shape in the phase change process and without containers for liquid PCM [27], shape-stabilised PCMs have been extensively researched.

Caiet al. [28] have prepared a composite shape-stabilised PCM based on paraffin (heat storage material)/high-density polyethylene (supporting material) under the twin-screw extruder technique. Besides, Sarı [29] has prepared another high-density polyethylene-based composite shape-stabilised PCM by melting and mixing method, and paraffin also serves as the heat storage material. Wang and Meng [30] have developed a composite shape-stabilised PCM, in which fatty acids were selected to be the heat storage material and the polymethyl methacrylate was as the supporting material, with the method of self-polymerization. The mass ratio of heat storage material in the total material was more than 50%, and the properties of PCMs were characterized by SEM, DSC, etc. Darkwa and Zhou [31] chose hexadecane and polyvinyl acetate to be PCM and supporting material, respectively, through laminating method, and aluminium serves as the additive to enhance the thermal conductivity.

As research continues, a concern in using shape-stabilised PCMs emerged. The mainly used PCMs, including paraffin and fatty acids, are flammable, and the supporting materials, such as high-density polyethylene and polyvinyl acetate, also easily catch fire [32,33]. The other way to prepare the shape-stabilised PCM is that the porous material was used to be the supporting material. Most of the porous materials are inorganic minerals, such as expanded perlite and expanded vermiculite, which are uninflammable. The micropores in this kind of supporting materials can absorb and contain the liquid PCMs, due to interfacial tension and capillary absorption [34].

In the early researches, the liquid PCM was directly immersed into porous building materials to form the composite PCM. In the works [35,36], the gypsum board was used to be the supporting material, and liquid fatty acids were immersed into them. This kind of composite PCM was available for peak load shifting in winter. However, the supporting material cannot absorb enough liquid PCMs with the simple immersion method. It is due to that the large number of micropores fully contain the air, which can prevent the absorption of liquid PCMs to micropores. So the air in the inner space of micropores should be drawn out, in order that the supporting material can absorb more liquid PCMs [23,37]. The vacuum impregnation method was widely used to remove the air of micropores in the preparing process of shape-stabilised PCM. Karaipekli and Sarı [38] have prepared the shape-stabilised PCM by incorporation of eutectic mixtures of fatty acids within the expanded vermiculite through vacuum impregnation method. The composite shape-stabilised PCM was characterized by SEM, FTIR and DSC methods. Jiao et al. [39] used a kind of binary eutectic mixture of fatty acids, which composed of lauric acid and stearic acid (70 wt%: 30 wt%), to prepare the composite PCM with supporting material of expanded perlite through the vacuum impregnation method, and they characterized the structure and properties of composite PCM. Besides, Zhang et al. [40] have developed another expanded perlite-based composite PCM with capric acid 85 wt%:palmitic acid 15 wt%, also using vacuum impregnation method.

The shape-stabilised PCM has been proved that it is available in building energy efficiency [41]. Currently, the researches about the shape-stabilised PCM mainly focused on the property study, including thermal properties, chemical stability and thermal reliability [38,42,43]. In this study, a novel CPCMW has been fabricated, and the thermal performance and mechanical property of CPCMW were characterized. Besides, the cold storage performance was experimentally studied in two rooms with the same size. The main composition of CPCMW was the expanded perlite-based PCM particle, which was prepared by shape-stabilised PCM method. Besides, it was different from other studies for the prepare process. Shape-stabilised PCM particles were prepared by a self-made novel vacuum heating rolling box, which can produce PCMs of 4 kg in each time.

2. Materials and methods

2.1. Materials

An important point of PCM used in building was the suitable phase change temperature range and enough latent heat capacity [44], especially for PCM used in the internal building envelope. A kind of paraffin produced by Nanyang Wax Fine Chemical company was used to be the phase change material, which has large latent heat. Besides, its onset melting is within the range of human body comfort. In order to improve the comfort of human body in buildings in the premise of reducing energy consumption, the materials fabricated by encapsulating the paraffin with supporting materials were incorporated with the building envelope, to passively adjust the indoor temperature.

The adsorption method, which refers to encapsulate PCM by the supporting material, is commonly used to prepare the phase change material [34]. Generally, the supporting material should have a large number of micropores and certain strength to firmly contain PCM. In this study, the expanded perlite, whose size is 3–6 mm (produced by Xin yang Licheng Perlite Factory),was selected to be the supporting material to fabricate the phase change material particle. EP is mainly composed of SiO_2,Al_2O_3 and Na_2O, which account for more than 90% of the total mass, and a small amount of MgO, GaO, etc. [45]. Because it has porous structures and larger specific surface area, PCMP can be prepared through liquid paraffin adsorbed into EP, with the capillary effect of micropores and the surface tension under the vacuum condition.

2.2. CPCMW preparation

In the first stage of study, a kind of vacuum adsorption facility including suction bottle, vacuum pump and heating magnetic stir-