Energy and Buildings 68 (2014) 703–706

Contents lists available at ScienceDirect

Energy and Buildings

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

New phase-change material components for thermal management of the light weight envelope of buildings

L. Karim[a,b], F. Barbeon[b], P. Gegout[b], A. Bontemps[c], L. Royon[a,c,*]

[a] Laboratoire des Systèmes Complexes, Université Denis Diderot, France
[b] Pole Ingénierie Matériaux, Bouygues, 78114 Magny les Hameaux, France
[c] Laboratoire Interdisciplinaire des Energies de Demain, Université Denis Diderot, France

ARTICLE INFO

Article history:
Received 5 February 2013
Accepted 27 August 2013

Keywords:
Phase-change
Latent heat
Paraffin
Thermal inertia
Energy storage

ABSTRACT

This work proposes the improvement of the energy performance of hollow concrete floor panel through the insertion of a phase change material (PCM) in enclosures of the floor panel in order to significantly increase the thermal inertia of the wall. The PCM is a shape-stabilized polymer composite PCM containing 85% of paraffin, with a latent heat of melting of 110 kJ/kg and a melting point at about 27 °C. This article shows first, the design and development of the floor panel including PCM, then presents the methodology of the experimental tests that were conducted to study the thermal performance of the floor panel. The obtained results were discussed and finally the most relevant conclusions are presented, as well as future basis of the investigation.

1. Introduction

To reduce the energetic dependence of buildings, it has become necessary to develop new materials or constructive systems that meet the requirements needed to promote both energy conservation and sustainability in construction. One way to reduce energy consumption is to increase the thermal storage of the structure in order to use the solar energy stored during the day and to reduce peak loads. The utilization of Phase Change Materials (PCM) in active and passive cooling/heating of buildings is one of the most efficient ways to store thermal energy. Different research projects have been developed since the last decade including (i) direct incorporation or impregnation of the construction material, (ii) incorporation of PCM capsules in building components, (iii) manufacturing new panels with PCMs to replace classic wallboards and, (iv) incorporation in a heat exchanger plate to improve performance of a HVAC system. The main projects can be found in recent reviews [1–6].

Nevertheless, different techniques presented in literature have limited success because it is difficult to incorporate these phase change materials into existing building. The main technical causes that prevents PCMs from being applied widely in practice comes the conditioning of the phase-change element materials. The material must be completely sealed to prevent leakage of the product during the melting process. Encapsulation and shape stabilization are two methods investigated recently to develop new mechanically stable composite PCM. For the first one, we distinguish micro-encapsulation technology to obtain PCMs particle of few micrometer diameter enclosed in a thin, sealed and high molecular weight polymeric film and macro-encapsulation technology with PCMs encapsulated in a container [7–9]. The second method consist to disperse PCM in a high density polymer supporting (as SBS, polyethylene etc.) to form a stable composite material. The shape-stabilized PCM obtained can keep its shape even when the phase-change element changes from solid to liquid [8,9].

To new construction element, an attractive method is to include PCMs inside cavities which could exist in construction components. This is the case of hollow bricks and several studies have proven such a method useful to increase thermal inertia of buildings [10–12].

One of the objectives of the present study is to implement either of the following to insure good protection against leaks, (i) to profit of existing cavities in construction elements to confine PCMs (ii) to use a composite which does not flow when the phase-change material is in the liquid state and we propose to consider in this work a home-made PCM composite which does not need any conditioning. This material, presented in first part, is manufactured by incorporating paraffin in a polymer matrix. During thermal cycling no leaks were observed when paraffin is in liquid state. With a melting temperature of 27 °C, the PCM is intended to be used in summer season in order to absorb the heat flow from outside to inside of the building.

* Corresponding author. Tel.: +33 0 1 57 27 62 52; fax: +33 0 1 57 27 62 52.
E-mail addresses: laurent.royon@univ-paris-diderot.fr, royon@univ-mlv.fr (L. Royon).

0378-7788/$ – see front matter
http://dx.doi.org/10.1016/j.enbuild.2013.08.056

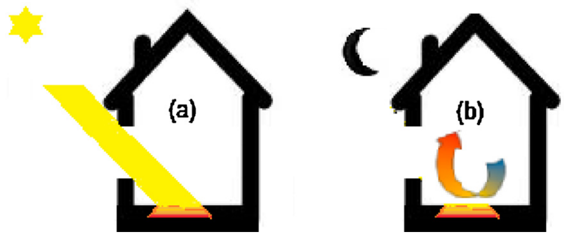

Fig. 1. Illustration of use of interior thermal mass in the floor panel filled formulated with PCM during daytimes (a) and night times (b).

Fig. 2. Image of the floor panel.

Though the integration of PCMs into light building components has been investigated in numerous studies, these components were essentially devoted to walls. To our knowledge the integration in floors or ceilings has rarely been studied [13–17].

This study concerns a new construction element: a hollow concrete floor panel with cylindrical holes filled with PCM composite. The purpose of the element is that during daytimes the PCM absorbs part of the heat from solar radiation through the process of melting (see Fig. 1a) and thus improves the thermal comfort in the room of the building without the need to use an air conditioning system. Such floors can better manage thereby solar gain entering the building principally through the windows. At night the PCM solidify and releases the stored heat (Fig. 1b). The present investigation is focused on the dynamic of the thermal heat transfer of a floor panel submitted to a heat-up ramp follow by a cool-down ramp. The results are compared to those obtained for reference floor panel in order to assess the effect of PCM. The analysis of data demonstrates the suitability of the new component to guarantee significant thermal inertia of a building's envelopes.

2. Presentation and design of the floor panel filled with paraffin-PCM composite

This part is a presentation of the alveolar floor panel filled with composite PCM and its thermophysical properties.

2.1. Presentation of the floor slab

Fig. 2 shows a photograph of the concrete hollow floor slab with eight cylindrical cavities. Thermo-physical properties of used concrete are given in Table 1. The slab dimensions are 28 cm × 28 cm × 3.75 cm. Each cavity is a cylinder which has a diameter of 2.5 cm and a length of 28 cm. The studied sample represents here a floor panel at the 1:5 scale.

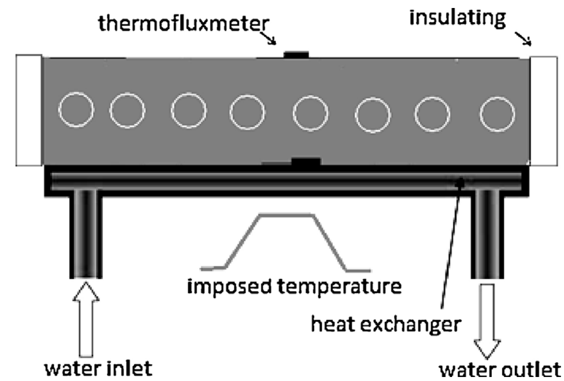

Fig. 3. Schematic of the experimental set up.

The PCM introduced inside each cavity of the concrete hollow floor is a shape-stabilized phase change material obtained by mixing at high temperature (>100 °C) paraffin which serves as a latent heat storage material and a styrene–butadiene–styrene (SBS) block copolymer polymer leading to a matrix acting as the supporting material. The paraffin is commercial grade wax obtained from petroleum distillation. This fusible material used here is a combination of $(CH_2)_{12}$, $(CH_2)_{13}$, $(CH_2)_{14}$, and $(CH_2)_{15}$. With a mass fraction of 15% of polymer, no liquid leakage during its solid-liquid phase change is observed. Thermo-rheological tests confirm good mechanical properties of the PCM under thermal cycles [18].

2.2. Thermo-physical properties

Thermal properties of the paraffin PCM and the concrete such as phase change enthalpy, specific heat and phase change temperature were measured by using DSC method applied with Mettler Toledo Co instrument through a thermal cycle of cooling-to-heating. The specific enthalpy of fusion for the PCM was found to be 110 ± 11 kJ/kg. Thermo-physical properties also were measured and are given in Table 1.

3. Experimental set up and procedure

An experimental device has been developed to apply identical temperature variation to floor panels with and without PCM. Referring to Fig. 3, one side of the floor panel is located in close contact with a heat exchanger, fed by a thermo-regulated water flow. The flow comes from a bath programmed to produce a prescribed linear variation of the water between 20 °C and 35 °C during 6 h, followed by temperature stabilization at 35 °C during 6 h, and then a linear variation of the water between 35 °C and 20 °C during 6 h. A rate of heating and cooling of 0.042 °C/min was fixed in order to be at about the same rate as it appears in real conditions. The opposite side is adjacent to a room in which temperature T_a is kept quasi-constant at 20 °C. On each side of the floor are placed temperature and flux sensors located inside a thermofluxmeter (Fig. 4). Thermocouples (type K) and fluxmeters were calibrated with a specific device. The floor panel was initially at uniform ambient temperature.

Table 1
Thermo-physical properties of the paraffin PCM and of concrete.

	Density, ρ (kg/m^3)	Thermal conductivity k W/(m K)	Specific heat capacity, C_p (J/(kg K))
PCM			
$T < 27.5$ °C	840	0.28	2800
$T > 27.5$ °C	771	0.18	2500
Concrete	2800	1	880