Energy and Buildings 126 (2016) 408–414

Contents lists available at ScienceDirect

Energy and Buildings

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

Research on temperature dependent effective thermal conductivity of composite-phase change materials (PCMs) wall based on steady-state method in a thermal chamber

Xu Wang, Hang Yu*, Lu Li, Mei Zhao

School of Mechanical Engineering, Tongji University, Shanghai 201804, PR China

ARTICLE INFO

Article history:
Received 31 January 2016
Received in revised form 9 May 2016
Accepted 19 May 2016
Available online 24 May 2016

Keywords:
Effective thermal conductivity
Phase change materials (PCMs)
Composite-PCMs wall
Temperature
Phase change amount

ABSTRACT

Effective thermal conductivity (λ) is the key factor in characterizing thermal conductance and temperature field when studying the thermal performance of composite-phase change materials (PCMs). But relevant research focusing on the influence of temperature on λ of composite-PCMs is scarcely reported. This paper aimed to examine the relationship between λ of a kind of prevalent composite-PCMs wall (λ_{pcw}) and temperature as well as the percentage of the phase-changed amount of the wall. In this research, two walls with a dimension of 1.5 m (W) × 1.5 m (H) and composed of cement mortar/shape-stabilized PCMs bricks, Portland vitrified bricks, respectively were built and tested by a steady-state method in a thermal chamber. Results showed a good positive linear relationship of λ with the increasing mean wall surface temperature for the regular vitrified brick wall as well as the composite-PCMs wall in solid and liquid states. In addition, as for the cases where the composite-PCMs wall partly experienced solid-liquid phase change, there was a negative proportional relationship between λ and the increasing percentage of the phase-changed part, which exhibited the major difference with that of the common walls.

1. Introduction

With the increasing amount of research on the application of phase change materials (PCMs) in building enclosures [1–5], it is of great importance to study the thermal properties of composite-PCMs, among which effective thermal conductivity (λ) is one of the most important parameters [3,6–8]. According to the Fourier's Law of thermal conductance [6], heat flow rate for a given temperature gradient is directly proportional to λ of the material. Therefore, in the analysis of heat conduction, λ is a critical parameter which determines the rate of heat flow in the medium [6–8].

In general, there are two methods to acquire λ of a certain material: theoretical and experimental methods [9]. It can be approximately predicted by a number of mathematical and physical models such as Maxwell model [10], Rayleigh model [11], Bruggeman model [12], Hamilton-Crosser model [13,14] and Hasselman-Johnson model [15]. But there are some restrictions for the application of these theoretical models based on some assumptions that simplify the micro-structure of the material [16], and none of which involve a temperature dependent thermal conductivity model. Therefore, λ is still prevalently obtained via experimental methods [16].

Effective thermal conductivity of a material can be measured by a number of possible ways, which are classified into two methods: steady-state and non-steady-state (or transient) methods [9,16]. In general, it is straightforward of the signal analysis for the steady-state techniques, which perform a measurement when the temperature of the material measured does not change with time. But the disadvantages are that a well-engineered experimental setup is usually needed and it often takes much time for the test [17]. As for the non-steady-state methods, it is not required for the signal to obtain a constant value. Instead, the signal is studied as a function of time since there is no need to wait for a steady-state situation so that the measurement can be performed more quickly. But the disadvantage is that the mathematical analysis of the data is usually more difficult [18,19]. However, temperature of the samples can not be accurately controlled or set at different values by regular thermal conductivity measurement apparatus.

Abbreviations: PCMs, phase change materials; SSPCMs, shape-stabilized phase change materials; HDPE, high density polyethylene; EG, expanded graphite; DSC, differential scanning calorimetry.

* Corresponding author.
E-mail address: tjyuhang@163.com (H. Yu).

http://dx.doi.org/10.1016/j.enbuild.2016.05.058
0378-7788/

Nomenclature

Symbols

λ	Effective thermal conductivity (W/(m K))
q	Heat flux (W/m^2)
T	Temperature (°C)
Δ	Difference
δ	Thickness (m)
R	Correlation coefficient
φ	Phase change factor
L	Length (m)
H	Height (m)
W	Width (m)

Subscripts

pcw	Composite phase change materials wall
comw	Common wall
l	Liquid
s	Solid
sur	Wall surfaces

PCMs-concrete, which is made by direct incorporation of PCMs into cement mortar [1,5,20], has been widely studied for the low thermal conductivity and incredibly high thermal storage capacity [21]. It is often made into the form of wallboard or brick and is often applied in the exterior building enclosure for energy saving [5]. But there is scarce research focusing on λ of this kind of composite-PCMs enclosures quantitatively influenced by temperature and the phase-change effect, which is particularly significant in the mathematical modeling and heat calculating processes for a numerical research.

Eddhahak-Ouni et al. [22] analyzed the influence of temperature and PCMs mass percentage on λ of a kind of PCMs-concrete by a hot-disk apparatus, but the test was only carried out under the conditions that the incorporated PCMs were in liquid stage. Results showed that λ decreased slightly with the increasing temperature of the sample. Inaba and Tu [23] studied the relationship between λ of a kind of composite-high density polyethylene (HDPE)/paraffin and temperature via a transient hot-wire method. It is pointed out that λ had a negative correlation with the increasing temperature, and declined sharply when the paraffin was in solid state and phase change process. Ye et al. [24] examined λ of a kind of composite-expanded graphite (EG)/paraffin by a laser flash apparatus. The test was carried out when the composite-PCMs was in solid and liquid states, and results showed a decrease of λ of the composite when the paraffin was in liquid state compared with that in solid state. It was also pointed out by Cole and Holmes [25] that λ of paraffin in solid state was generally greater than that in liquid state.

Unlike crystalline materials which have a definite melting point, organic PCMs such as paraffin wax have a quite wide phase change temperature range during which the state is difficult to describe and the variation of λ is also hard to quantify. Moreover, it is more difficult to analyze λ as a function of temperature of composite-PCMs enclosures because of the different physical properties of the constituents. In addition, the volume of paraffin wax, generally speaking, will expand with the increasing temperature [25], and the findings on expansion coefficient of paraffin [25,26] revealed that the expansion of volume mainly appeared in the solid-liquid phase change stage, which made the quantification of λ of the composite-PCMs more complicated during that stage.

In this study, a thermal chamber which is a kind of prevailing equipment for testing the thermal performance of walls or other building materials was applied to test λ of a kind of composite-PCMs wall by steady-state method. Compared with conventional methods, it is much more complicated and expensive for the testing process due to the fact that a wall with a dimension of 1.5 m (W) × 1.5 m (H) must be built and tested for a long time. But advantages are that temperature of the wall can be accurately controlled and set at different values, and the testing environment is much closer to the real circumstances where a wall is built. Thus, as long as the parameters involving the wall surfaces temperature and heat flux as well as the wall thickness could be accurately measured, λ of the wall could be precisely acquired under different temperature conditions. Therefore, influence of temperature on λ of the composite-PCMs wall (λ_{pcm}) can be quantitatively analyzed.

Fig. 1. Photograph of the SSPCMs.

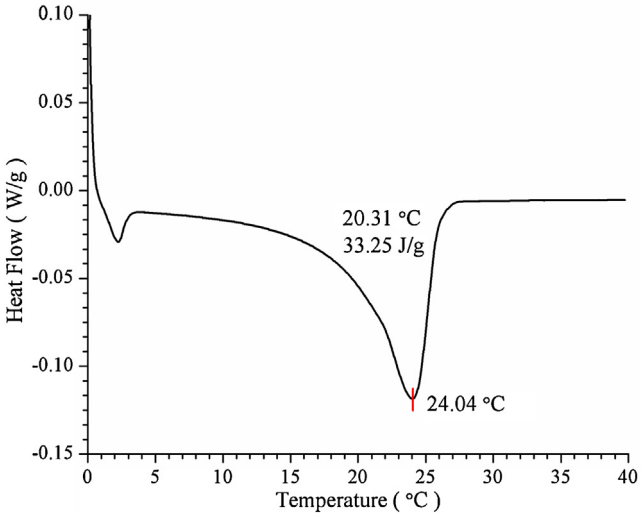

Fig. 2. DSC curve of the SSPCMs.

2. Materials and method

2.1. Composite-PCMs wall and common wall

The tested product of GH-20 [27] was a kind of shape-stabilized PCMs (SSPCMs) with a particle size of 0.5–5 mm and was shown in Fig. 1. The composite-PCMs were constituted of 70 wt% of paraffin, 15 wt% of HDPE and 15 wt% of EG. Three samples were randomly selected with a quantity of about 15 mg, and were tested by a differential scanning calorimetry (DSC, model: Q100 V9.9 Build 303) with a heating rate of 0.7 °C/min. A good agreement was observed among the results, and the average DSC curve was displayed in