Renewable and Sustainable Energy Reviews 57 (2016) 916–928

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Advanced energy storage materials for building applications and their thermal performance characterization: A review

Tumirah Khadiran [a,b], Mohd Zobir Hussein [a,*], Zulkarnain Zainal [a], Rafeadah Rusli [b]

[a] Material Synthesis and Characterization Laboratory (MSCL), Institute of Advanced Technology (ITMA), Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

[b] Forest Product Division, Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form
17 October 2015
Accepted 17 December 2015

Keywords:
Thermal energy storage
Phase change materials
Building
Energy saving
Temperature

ABSTRACT

Advanced energy storage technology based on phase change materials (PCMs) has received considerable attention over the last decade for used in various applications. Buildings are the major industry which needs this advanced technology to improve internal building comfort and the reduction of energy usage. However, the main barrier which affects the application of this technology in building sector is the method to incorporate the PCMs into the building materials and the method used to measure the effectiveness of the PCMs as TES in building. In this paper, a review on the TES systems based on PCMs, their thermo-physical and chemical properties, and potential application as TES for buildings have been carried out. The methodologies for the incorporation of PCMs into the building materials, and their thermal performance are discussed.

Contents

* Corresponding author. Tel.: +603 89468092; fax: +603 89467006.
E-mail address: mzobir@upm.edu.my (M.Z. Hussein).

http://dx.doi.org/10.1016/j.rser.2015.12.081

1. Introduction

The fast economic growth and high standards of living imposed the world to consume large amount of conventional energy resources (fossil fuels) that drive environmental pollutions and climate changes. In addition, the dependency towards conventional energy resources will empties the sources more rapidly. Therefore, the effectiveness utilization of energy becomes a main issue recently. Various renewable energy systems were developed to enhance energy efficiency such as thermal energy storage (TES) system. TES is the temporary energy storage medium for later used. It provides realistic solution to increase the efficiency of the energy utilization and management. This technology is an elegant energy technology which can be used in various industries especially building industry [1–4].

TES system consists of sensible heat storage, chemical heat storage and latent heat phase change materials (PCMs). However, TES based on PCMs is lately gaining an increasing interest due to their advantages such as high storage density and constant temperature during phase change. In addition, TES based on PCMs shows the potential to shift electricity peak load which beneficial to reduce energy usage in buildings.

A large number of researches have been done on the preparation and application of PCMs into buildings. In general, the studies can be grouped into four which are design and development of PCMs as TES materials, method for incorporation of PCMs into buildings materials, locations of the applications and the method used to measure the effectiveness of the PCMs as TES in buildings.

In buildings, PCMs can be incorporated either into the walls, ceiling, roofs and floors. Based on the laboratory experiment, it was reported that the TES of the gypsum wallboard can be increase ten times by incorporation of PCMs [5]. Concrete incorporated 5% microencapsulated PCMs reported can save energy up to 12% [6]. Several authors measuring the performance of walls, ceiling and floors incorporated PCMs by exposed to outdoor weather conditions and the reductions in room temperature fluctuation were observed. Kissock et al. [7] reported that 10 °C reductions in peak daytime temperature were observed when wallboard incorporated with 30% commercial paraffin was used. Pasupathy et al. [8] studied the feasibility of using PCMs in building structures including wood-lightweight concrete frame walls, concrete block, windows and dry walls. They concluded that TES based on PCMs technology integrated in building would be of great importance energy systems in the future.

The previous findings shows that the PCMs integrated into building components work well for keeping the internal buildings within thermal comfort. However, not all PCMs are suitable to be used for building applications. The different methods used to incorporate PCMs into the buildings have different advantages and disadvantages. In addition, a lot of parameters should be taken into account during study the thermal performance characteristics of the PCM-incorporated building materials.

The objective of this paper is; (a) to present a comprehensive state-of-the-art of PCMs that can be function as TES material, including desirable properties governing the selection of PCMs as TES materials for buildings, (b) to explore possible incorporation technique (passive or active system) of the PCMs into the building envelope and the thermal evaluation method used to measure the effectiveness of the PCMs as TES in buildings. This paper may help developing guidelines for a thermal performance testing design and point to future research possibilities on TES based on PCMs.

2. Thermal energy storage (TES)

TES can be classifies into three main groups based on the thermal storage mechanism which are sensible heat storage, latent heat storage and chemical heat storage. Fig. 1 shows the TES classifications.

2.1. Sensible heat storage

TES system based on sensible heat storage, energy is stored by changing the temperature of the employed materials. The sensible heat storage materials undergo no change in their phase over the temperature range. The main advantages of these systems are low cost and long working stability. The amount of heat stored in a mass of employed materials can be expressed as

$$Q = mc_p\Delta T = \rho c_p V\Delta T \quad (1)$$

where c_p is the specific heat of the storage material, ΔT is the temperature change, V is the volume of storage material, and ρ is the density of the materials [9]. Based on the Eq. (1), shows that the ability to store sensible heat for a given material strongly depends on the value of the ρc_p. Therefore, materials with high density and high heat capacity have high possibility to bear high temperature changes.

Sensible heat storage material can be classified into two based on the basis of storage media as (1) liquid storage media and (2) solid storage media [10]. Some common sensible heat storage materials and their properties are presented in Table 1. The most common sensible heat storage materials used is water. Water offered highest thermal energy storage capacity, inexpensive and readily available. However, its major drawbacks includes: (1) system corrosion and leakage, (2) requires costly insulation due to the high vapor pressure of the materials, (3) need large size and large temperature swing during the addition and extraction of energy [11]. Water usually used as a cold TES. The cold TES technology delivers chilled water to buildings like offices, factories and *etc*. Malaysia used cold TES technology for cooling system in the commercial building such as The Bangsar District Cooling Plant which serving various commercial building including Telekom Tower and TNB Head Quarters [9], and University Kebangsaan Malaysia (UKM) District Cooling Plant serving 10 faculties within the university. Others commercial building which used this technology includes Malaysian Institute of Nuclear Technology (MINT), Hospital Serdang, Institute Jantung Negara (IJN), 1 Borneao and Putrajaya Precint 1 (P1). Fig. 2 shows the cold TES technology which set up in Bangsar and UKM.

Petroleum based oils and molten salts are also commonly proposed materials as substitute to water [14]. The heat capacities are 25–40% of that of water on a weight basis. This materials also have lower vapor pressure than water and capable of operating at high temperatures exceeding 300 °C. However, it is limited with the stability and safety problem and high in cost. In addition, it is highly corrosive, and there is a difficulty in containing it at high temperature [14].

Solid materials such as wood, rocks, concrete, sandstone, bricks, *etc*., can be used as sensible heat storage materials for low