Energy 59 (2013) 194–214

Contents lists available at SciVerse ScienceDirect

Energy

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

Energy efficient hybrid nanocomposite-based cool thermal storage air conditioning system for sustainable buildings

R. Parameshwaran [a,b], S. Kalaiselvam [a,c,*]

[a] Department of Mechanical Engineering, Anna University, Chennai – 600 025, India
[b] Centre for Nanoscience and Technology, Anna University, Chennai – 600 025, India
[c] Department of Applied Science and Technology, Anna University, Chennai – 600 025, India

ARTICLE INFO

Article history:
Received 10 November 2012
Received in revised form
20 May 2013
Accepted 24 June 2013
Available online 30 July 2013

Keywords:
Energy efficiency
Energy savings potential
Hybrid nanocomposites
Phase change material
Thermal energy storage

ABSTRACT

The quest towards energy conservative building design is increasingly popular in recent years, which has triggered greater interests in developing energy efficient systems for space cooling in buildings. In this work, energy efficient silver–titania HiTES (hybrid nanocomposites-based cool thermal energy storage) system combined with building A/C (air conditioning) system was experimentally investigated for summer and winter design conditions. HiNPCM (hybrid nanocomposite particles embedded PCM) used as the heat storage material has exhibited 7.3–58.4% of improved thermal conductivity than at its purest state. The complete freezing time for HiNPCM was reduced by 15% which was attributed to its improved thermophysical characteristics. Experimental results suggest that the effective energy redistribution capability of HiTES system has contributed for reduction in the chiller nominal cooling capacity by 46.3% and 39.6% respectively, under part load and on-peak load operating conditions. The HiTES A/C system achieved 27.3% and 32.5% of on-peak energy savings potential in summer and winter respectively compared to the conventional A/C system. For the same operating conditions, this system yield 8.3%, 12.2% and 7.2% and 10.2% of per day average and yearly energy conservation respectively. This system can be applied for year-round space conditioning application without sacrificing energy efficiency in buildings.

1. Introduction

Energy, the integral source for all human-based activities has to be conserved at every step in the technological and societal development. The growing challenges and concerns on energy and environment have paved way for the development of several energy saving measures in engineering systems worldwide. The statistical report of IEO (International Energy Outlook) 2010 [1] infers that the sectors of transportation, industry and residential consumes about 30%, 29% and 27% of energy respectively.

The estimated global annual primary energy consumption in buildings is presented in Table 1 [2,3]. It can be seen from the projections that the building energy consumption is forever a growing mechanism, which creates more opportunities for the development of energy efficiency systems that may be implemented for acquiring enhanced energy efficiency in buildings.

One effective way to confront this challenge is to redistribute or shift the cooling energy requirements between on-peak load and part load conditions using LTES (latent thermal energy storage) systems. These systems are primarily included with heat storage material usually referred as PCM (phase change material) which has the capability to store and release large amount of thermal energy by means of phase transition at near isothermal conditions. Many research studies have been reported on TES systems utilizing PCM for improving the thermal energy storage performance and energy efficiency in cooling and heating systems [3–13].

Cho and Choi [14] explained the heat transfer characteristics of paraffin-based PCM through numerical and experimental analysis. The thermal properties of paraffin-PCM contained in spherical capsule were determined and its appropriateness for building cooling/heating applications was suggested. Tian and Zhao [15] studied the heat transfer characteristics of PCMs embedded in porous metals and suggested that use of metal foams with smaller porosities and bigger pore densities would enhance the heat transfer process in PCMs.

* Corresponding author. Department of Applied Science and Technology, Anna University, Chennai - 600 025, India. Tel.: +91 4422359220; fax: +91 4422301656.
E-mail addresses: parameshviews@gmail.com (R. Parameshwaran), kalai@annauniv.edu, nanokalai@gmail.com (S. Kalaiselvam).

0360-5442/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2013.06.064

Table 1
Estimated global annual primary energy consumption by buildings [2,3].

Year	Energy consumption (EJ/year)
2004	76.2
2010	86.7
2015	95.7
2020	102.7
2025	108.9
2030	115.7

MacPhee et al. [16] performed the numerical simulation and exergetic performance assessment of solidification process in an encapsulated ice TES system and concluded that by increasing the inlet flow rate and temperature of heat transfer fluid, the rate of freezing could be fully achieved. In addition, the energy efficiencies achieved in this system was above 99.6% whereas, the exergetic efficiencies ranged from 78 to 92%. Exergetic efficiencies-based methodology gave good understanding of system losses rather than energy efficiencies.

Wu et al. [17] demonstrated the significance of heat transfer mechanism and thermal response of CTES (cool thermal energy storage) system containing PCM being subjected to transient load conditions during freezing and melting processes. Sebzali and Rubini [18] investigated chilled water storage system for advancing the energy performance of ACC (air cooled chillers) serving the cooling load requirements for building located in Kuwait. Henze et al. [19] designed an LTES system combined with chilled water plant for pharmaceutical buildings which paved way for improved thermal efficiency and performance of the chilled water plant.

Boonnasa and Namprakai [20] described the energy savings potential of chilled water storage system for an academic building located in Thailand. Albeit several kinds of PCM exists, the organic ester PCM are a class of heat storage material that possess good thermophysical properties, high latent heat capacity, stability and reliability on long term use. In this perspective, graphite additives in the form of flakes were doped into the organic PCM which has improved the thermal conductivity and energy storage density of such PCM [21,22].

However, these additives in micron size been incorporated into PCM in large weight proportions may tend to reduce the thermal energy storage characteristics over several thermal cycles. The scenario of incorporating nanomaterials of size 1–100 nm into pure PCM has been increasingly attractive for improving the thermophysical properties and heat storage capabilities. Nanostructures prepared with different shapes and profiles including nanorods, nanotubes, nanofibers, nanowires, nanobundles etc., have rendered variety of thermophysical property changes while they are doped in base PCM [23,24].

Carbon nanostructures including carbon nanotubes were considered to be an essential additive for augmenting heat transfer and energy storage characteristics of PCM [25–29]. Apart from carbon and graphite nanostructures, researchers worldwide have also performed detailed analytical and experimental studies on metallic and metal-oxide nanoparticles infused PCM [30–34]. They signified the importance of mass fraction of such nanoparticles that influenced the thermal conductivity, latent heat capacity, freezing and melting characteristics of PCM. In short, PCM containing increased mass fractions of nanoparticles or nanostructures has shown the thermal conductivity to get improved by 50–60% than at its pure state, which in turn facilitated them to have reduced freezing and melting times.

In the present work, a new HiTES A/C (hybrid nanocomposite-based TES system combined with building air conditioning) system was experimentally investigated for summer and winter design conditions. The combined thermal performance and energy storage characteristics obtained during on-peak and part load conditions enabled HiTES A/C system to exhibit energy efficiency while compared to conventional A/C system. Referring to the past literatures and to the best of our knowledge, HiTES system makes itself distinct in the class of partial storage TES systems, which could be beneficial in terms of providing efficient cooling load redistribution and energy efficiency in modern buildings.

2. System description and work methodology

2.1. Preparation and characterization of HiNPCM

Preparation of silver–titania HyNC (hybrid nanocomposites) was executed through the ultrasonic dispersion of anatase form of titanium dioxide or titania (TiO_2) and subsequent reduction AgNP (silver ions to nanoparticles) over the surface of TiO_2 by sol–gel procedure using suitable reducing agents as prescribed in Ref. [35]. In the steps of preparing HiNPCM, hybrid nanocomposite powder was redispersed in pure (base) PCM in mass fractions varying from 0.05% to 1.5% using the ultrasonic vibrator (UP200S-Hielscher).

Appropriate mass fractions of hybrid nanoparticles in PCM (Dimethyl adipate – DMA) were obtained using the electronic balance (Denver Instruments, precision: 0.0001 g). As-prepared HiNPCM was used in the experiment and its energy storage and discharge abilities were assessed for it to be configured into the HiTES A/C system. HiNPCM tested for several thermal cycles was stable and reliable without forming any sedimentation or precipitation. The details of materials testing techniques used for HiNPCM characterization in Table 2.

High resolution FESEM (field emission scanning electron microscope) (FESEM, SUPRA®55, Carl Zeiss, Germany) and TEM (transmission electron microscope) (TEM, Technai 10 Philips)

Table 2
Details of materials testing techniques used for HiNPCM characterization.

Instrument for characterization	Model & make	Nature of test sample	Specifications	Testing source/method
FESEM (field emission scanning electron microscope) with EDAX (energy dispersive X-ray analysis)	SUPRA®55, Carl Zeiss, Germany	Powder	Electron high tension: 0.1 to 30 kV WD: 8.7 mm Range: 12 to 900,000x Signal A: InLens	Ultra high intensity electron beam & X-ray
Transmission electron microscope	Technai 10 Philips	Solution	Electron beam intensity: 20–200 kV	High intensity electron beam
DSC (differential scanning calorimetry)	NETZSCH DSC 200F3, Germany	Solution	Temperature range: −170 °C to 600 °C Scanning rate: 0.001 K/min to 100 K/min Temperature accuracy: 0.1 K Enthalpy accuracy: <1%	Furnace heating/cooling
Thermal conductivity	NETZSCH LFA 447 NanoFlash, Germany	Solution	Measurement range: 0.1 $W\ m^{-1}\ K^{-1}$ to 2000 $W\ m^{-1}\ K^{-1}$ Accuracy: ±3%	Laser beam/short light pulse flash method