Case Studies in Thermal Engineering 4 (2014) 175–186

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

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

Energy reduction of building air-conditioner with phase change material in Thailand

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ARTICLE INFO

Article history:
Received 30 August 2014
Received in revised form
13 September 2014
Accepted 30 September 2014
Available online 13 October 2014

Keywords:
Air-conditioner
Phase change material
Paraffin waxes
Thermal energy storage
Thermal performance

ABSTRACT

In this study, a concept of using phase change material (PCM) for improving cooling efficiency of an air-conditioner had been presented under Thai climate. Paraffin waxes melting point at around 20 °C was selected to evaluate the thermal performance by reducing the air temperature entering the evaporating coil. The model of PCM celluloid balls had been performed with the air-conditioner. Moreover, the mathematical model of the air-conditioner with the PCM storage was developed and verified with the testing results. From the study results, it could be seen that the simulated data agreed quite well with the experimental result at the discrepant around 2–4%. Finally, the model was used to analyze the economic result which was found that the electrical consumption of the modified air-conditioner could be decreased 3.09 kW h/d. The electrical power consumption of the modified unit was 36.27 kW h/d at the operating time 15 h/d compared with 39.36 kW h/d of the normal unit at the operating time 12 h/d. The saving cost of the PCM bed could be 9.10% or 170.03 USD and the payback period was 4.15 y.

1. Introduction

Phase change material (PCM) for using in office building is studied in various literature by applying for heating and cooling processes. In the heating process, PCM is used to warm the air before entering the room which reduces the electrical power of the air heater as presented by Kedl and Stovall [1], Salyer and Sircar [2] and Neeper [3,4]. For the cooling process, the main electrical energy consumption is devoted to air-conditioning system. Therefore, it is necessary to find techniques those could be used to reduce the load of the machine or to enhance its performance. Some researchers have used phase change material (PCM) as a tool to reduce cooling load by utilizing the cool ambient air in the nighttime which is used to charge the latent heat capacity of the PCM by freezing the material and the stored energy is released back to the occupied space to handle the heat gains during daytime.

Using of PCM in the energy building has been presented in many literatures. Uros et al. [5] presented an alternative method of cooling and ventilating buildings by integrating PCM into ceiling board of a building. Outside cool night air could be introduced into the space and it was used to cool the building interior and the PCM storage. During the daytime, hot indoor air was circulated in the room and the use of PCM was to absorb cooling load and reduced the room temperature. Some calculations were performed in different cities and it could be found that this technique could reduce energy for cooling between 10 and 87% depended on the air flow rate. Arkar et al. [6] designed a latent heat storage (LHTES) integrating

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http://dx.doi.org/10.1016/j.csite.2014.09.006

Abbreviations and symbols

Nomenclature

A	area, (m^2)
Cp	specific heat capacity, (kJ/kg K)
D	diameter, (m)
e	the correction space value of PCM ball bed (Void faction)
G	mass flow rate per area, (kg/s m^2)
h	enthalpy, (kJ/kg)
h_v	convection heat transfer coefficient, (W/m^3 K)
$\dot{m}$	mass flow rate, (kg/s)
T	temperature, (°C)
W	work, (kW)
x	distance, (m)
Q	heat capacity, (kW)

Greek symbol

ρ	density, (kg/m^3)

Subscript

a	air
AC	air-conditioner
ave	average
amb	ambient
b	bed
$Comp$	compressor
e	electrical power
E	evaporator
i	input
L	liquid
n	node
o	output
PCM	phase change material
S	solid
Sys	system
th	thermal
r	room

into a mechanical ventilation system. The storage medium was a type of paraffin encapsulated in spheres. The LHTES stored coldness of ambient air during the night and supplied it with time delay during the day thus free cooling was obtained. A case study of a low energy one family building in Slovenia was carried out. The technique maintained the room temperature to be lower than that of the ambient temperature and the free cooling helped reducing the size of mechanical ventilation system. Since PCM could act as thermal energy storage in buildings. The storage medium could store coolness using nighttime cheap electricity and the coolness could be used during daytime for space cooling. Yamaha and Misaki [7] proposed an air distribution system with PCM in air ducts for peak load shaving. The PCM storage was charged from 5:00 am to 8:00 am (the charging mode) by the air flowing in the closed loop of the PCM storage tank and the air conditioner to solidify the storage medium. When the charging operation finished, the ordinary air-conditioning operation started, in which the air was bypassed the PCM storage tank and fed into the occupied room. The discharging operation was occurred from 13:00 pm to 16:00 pm. At this mode, the air after the air-conditioner at a temperature slightly higher than that of the PCM melting point would flow through the PCM tank and the room, respectively. The simulation study based on a part of one floor of an office building in Japan showed that the use of 400 kg PCM for a room with an area of 73.8 m^2 surface could maintain a constant indoor temperature without using any cold source in a hot summer day. The melting temperature suitable for the system was around 19 °C, which could be achieved by MT 19.

In this study, a concept similar to Yamaha and Misaki [7] was considered with the climate of Chiang Mai, Thailand which was hotter than that of Japan and the countries reported in the literatures. The design of the PCM bed was a pack of PCM balls similar to that of Arkar et al. [6]. A set of tubes as a by-pass for air flowing to reduce the pressure drop was respected combining with the PCM bed. An experimental study was performed in a tested room with a cooling load around 2 TR and the electricity cost for the normal system and the system with the PCM had been investigated.

2. Materials and methods

In this study, paraffin waxes melting point at 20 °C (Rubitherm20, RT-20) was selected to be the storage medium to improve the cooling performance of the air-conditioner because the melting temperature point of PCM was lower than the return air temperature and it was higher than the supply air in the charging mode. The property of PCM is given in Table 1 and Fig. 1. Fig. 2 also shows the PCM ball in this experiment which is made from celluloid and contained the paraffin waxes into the PCM ball at around 70% by volume.

Table 1
Descriptions of the paraffin waxes property [8–10].

Paraffin	Properties
Paraffin melting peak point (°C)	22
Freezing peak point (°C)	20
Heat of fusion (kJ/kg)	160–180
Density liquid (kg/l)	0.75
Volume expansion	10%