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Heat transfer and pressure drop studies on a PCM-heat exchanger module for free cooling applications

V. Antony Aroul Raj [a], R. Velraj [b,*]

[a] Department of Mechanical Engineering, Easwari Engineering College, Chennai, India
[b] Department of Mechanical Engineering, Anna University Chennai, Chennai, India

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ABSTRACT

Free cooling/Night ventilation is the process of storing the cool energy available in the night time ambient air in a storage device. During the day time the cool energy is retrieved from the storage device in order to cool the building using mechanical ventilation system. The modular heat exchanger developed in this work is a shell and tube type with phase change materials in the shell portion of the module and passage for the flow of air through the tubes. The modules of the modular heat exchanger are stacked one over other with air spacers in between each module. This modular heat exchanger arrangement is suitable for free cooling application where the diurnal temperature variation is low. Transient and steady state CFD modeling is carried out for a single module and two air spacers. Conjugate heat transfer analysis is carried out for the fluid and PCM of heat exchanger module. The latent heat value of the PCM is modeled using apparent heat capacity method with suitable profile approximated from the experimental results. The CFD results are validated with the experimental results. The steady state CFD analysis is useful to determine the pressure drop across the module and the spacers and to know the flow and temperature variation of heat transfer fluid in the module so as to select the geometrical and flow parameters for a given surface temperature and inlet condition. The transient analysis results are useful to determine the PCM solidification characteristics and to verify the suitability of the selected geometrical dimensions. The air spacers provided between the module increases the retention time of the air for better heat transfer and its effect is more pronounced at the lower velocities and decreases as the frontal velocity increases and its effect is negligible above the frontal velocity of 2 m/s.

1. Introduction

A comfortable home with minimum energy consumption is the dream of the common people, governments and researchers. Earlier the researchers were interested in reducing the cost of energy and save the depleting fossil fuels. However recently the motivation has changed from these goals toward minimizing the carbon dioxide emission from the environmental perspective. Hence energy efficiency, use of clean and renewable energy has gained major attention by the researchers and policy makers of the developed and developing countries.

There are various methods adopted for passive cooling of buildings. Night ventilation is one such method by which the structural components are cooled, thus providing reduced temperature of indoor air conditions for the following day. In places where the daily variations of the ambient temperature are high, night ventilation is highly suitable. In free cooling, apart from sensible storage system, the latent heat thermal energy storage system (LHTES) is also used as storage medium which stores the coldness of the ambient air during early morning and supplies it with a time delay during the day. Phase change materials become the natural storage options because of the small temperature difference between day indoors and night outdoors. Free cooling concept is site specific and climate dependent. Free cooling is suitable for the less humid interior and desert regions. The benefit is less in the coastal area because temperature moderation is done by sea and land breeze. In the recent years experimental investigation have been conducted and reported by few researchers on the studies of feasibility of free cooling for various locations with various geometries of PCM-heat exchanger and PCM encapsulation. Flat plate encapsulate was used by Zalba et al. [1] to study the feasibility of free cooling with PCM melting temperature of around 20–25 °C. The parameters influencing charging and discharging time were discussed in detail. Nagano et al. [2] embedded PCM directly on the floor board in the form of granules of several mm in diameter. Arkar et al. [3–5] suggested a single cylindrical LHTES

* Corresponding author. Tel.: +91 44 2235 8051; fax: +91 44 2235 1991.
E-mail addresses: velrajr@annauniv.edu, velrajr@gmail.com (R. Velraj).

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