Applied Thermal Engineering 148 (2019) 466–477

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Numerical and experimental studies of a Capillary-Tube embedded PCM component for improving indoor thermal environment

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HIGHLIGHTS

- A simplified numerical model for Capillary Tubes embedded in a Phase Change Material (CT-PCM) system is developed.
- Both numerical and experimental studies are carried out.
- The numerical model has been verified with experimental data.
- The model can be used to test the energy saving potential of such CT-PCM system in different climates.

ARTICLE INFO

Keywords:
PCM
Hydronic radiant system
Low grade energy
Capillary tube
Building energy saving

ABSTRACT

This paper aims to analyse the thermal characteristics of a novel system of Capillary Tubes embedded in a Phase Change Material (CT-PCM) as part of active building environmental design for energy conservation and the improvement of indoor thermal environment. The CT-PCM system is proposed based on the concept that low-grade energy utilisation potential could be harnessed and maximised by buildings' radiant heating/cooling systems and phase change material. The CT-PCM component is first built in the laboratory, and the thermal characteristics of the CT-PCM are investigated through a set of thermal response experiments. In addition, a simplified model is developed to assess the long-term thermal performance of the CT-PCM system for its application during a strategical system design stage. To ensure the robustness of the numerical model in the assessment of the thermal performance of the system, the developed model is evaluated against the experiments under a set of dynamic thermal boundary conditions. The evaluation process revealed that when the flow rate of thermal fluids in the CT-PCM system is more than 800 ml/min, the simulation results of the proposed simplified model is in a good agreement with the experiment. When the flow rate in the capillary tube is smaller than 800 ml/min, the correction factors are derived to address the non-uniformity of temperature distribution.

1. Introduction

The application of active radiant systems for heating in winter and cooling in summer has expanded in recent years [1,2]. In some cases, radiant cooling/heating systems could potentially save up to 30% of the energy consumption comparing with traditional convective heating/cooling systems [3,4]. Construction of an active system may consist of pipes/tubes embedded in concrete slabs/floors/roofs where heat is allowed to exchange with the surrounding and the fluid. One example of an active radiant heating system is the Thermally Activated Building System (TABS) [5]. TABS utilises a water piping system embedded in building structures to store thermal energy. The heat stored in building structures (slabs/concretes) carried by the water will then exchange heat passively to enhance indoor thermal comfort. TABS with high thermal inertia is well-known for its peak load shifting ability as well as operating on low cost periods [6,7]. This helps to prolong the intermittent availability of renewables such as night-time cooling and solar radiation when these sources are no longer available [8]. Up to 30% of improvement in energy efficiency was reported when a system comprised of pipe-embedded roof/wall is coupled with low-grade energy [9]. One downside to the application of TABS is that it requires massive building structure (thermal mass) for thermal storage. For the system to

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https://doi.org/10.1016/j.applthermaleng.2018.10.041
Received 3 July 2018; Received in revised form 12 September 2018; Accepted 9 October 2018
Available online 09 November 2018
1359-4311/