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Experimental investigation on the heat transfer performance and water condensation phenomenon of radiant cooling panels

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ABSTRACT

Radiant cooling system is a promising technique, which is suitable for independent control processes of temperature and humidity. The two main benefits of radiant cooling systems include the potential to save energy and improvement of indoor thermal comfort. However, both the poor heat transfer performance and condensation below dew point temperature restrict the widespread utilization in the residential buildings especially in humid environment. This research was focused on comprehending detailed performance of the radiant cooling panel when it used as an air conditioning system. Three radiant cooling panels with the area of 0.16 m^2 were prepared for investigation and a constant temperature and humidity environment chamber employed to simulate the different indoor thermal environments. The heat transfer performance and moisture condensation phenomenon of the radiant cooling panels were investigated. The results showed that the flow state of chilled water had the biggest influence on the heat transfer performance of the radiant cooling panels. The temperature difference between chilled water and the ambient was also observed to significantly affect the performance. Condensation of moisture on the radiant cooling panels was noted to increase the heat transfer quantity, but posed a challenge in using of the radiant cooling panel. Taking the performance of heat transfer and moisture condensation into consideration, the gypsum radiant cooling panel showed the best performance as compared to the metal radiant cooling panel and pure tube panel. The radiant cooling panels can work more efficiently especially when proper control strategies are employed to avoid condensation.

1. Introduction

Cooling and heating systems in buildings consumes vast quantities of energy to provide acceptable standards of thermal comfort. With increased use of conventional energy sources in buildings, the world is now facing a great challenge to cut down on environmental pollution. Many researchers are now working on different projects to find out the best solutions to these challenges. Currently, more and more attention has been directed to radiant cooling/heating systems because they have been proven to be potentially more energy efficient than conventional air conditioning systems [1,2] and can provide improved thermal comfort environment [3,4]. In addition, previous research shows that radiant cooling/heating offers flexible possibilities to incorporate renewable energy sources in driving the system as well as integration with other systems to provide required thermal comfort [5]. Although substantial work has been and is still being done towards full realization of these benefits, more work needs to be done to optimize heat transfer and fully avoid or minimize the water condensation challenges especially in humid conditions.

Despite the facts that several researchers have developed models to solve some problems related to the correct design of the radiant cooling/heating systems [6], some uncertainties still remain especially as it regards to thermal behavior under hot and humid environment. Ren et al. [7] established a three dimensional model to investigate the heat transfer of radiant cooling/heating system and its suitability to employ renewable energy sources for heating and cooling. The analysis revealed that a supply of warm water temperature of 22 °C in winter and chilled water temperature of 17 °C in summer can meet the standard indoor heating and cooling requirements, respectively. Eusebio et al. [8] compared the comfort

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level of the ceiling cooling system, the floor cooling system and the wall cooling system, which were the three usual radiant cooling types. The results showed that the ceiling cooling provided better comfort levels than radiant wall cooling. The results further showed that the indoor thermal comfort level were even higher when the radiant ceiling cooling and radiant floor cooling operated together with radiant wall cooling system. Chiang et al. did an extensive computational fluid dynamics (CFD) studies based on an experimental radiant cooling ceiling system integrated with a mechanical ventilation system in a typical office and validated typical conditions by comparing the results to the field measured data in the actual room. The results showed that installation of a radiant cooling ceiling system integrated with a mechanical ventilation system in hot and humid re could affect or complement each other. Memon et al. [9] carried out both field assessment survey and TRNSYS simulation to study the performance of the radiant cooling system. The survey showed that more than 80% of occupants were satisfied at an effective temperature of 32.5 °C, which is 6.5 °C higher than the upper boundary of ASHRAE thermal comfort zone. It was also estimated that up to 80% of energy can be saved when radiant cooling is used to substitute conventional air conditioning systems to achieve indoor thermal comfort. Furthermore, radiant cooling was considered to improve thermal comfort level owing to a lower temperature gradient, inside the room, as compared with the traditional all-air system. Tian and Love [10] reported that the main advantage of radiant cooling was found to be reduced local thermal discomfort with reduced vertical air temperature difference as well as reduced draft rate. Catalina et al. [11] reported a full-scale experiment and a computational fluid dynamics (CFD) study of a radiant cooling ceiling system to analyze factors that influence indoor thermal environment, i.e. air temperature, surface temperature and global temperature. The results obtained showed that within the ankle/feet zone the air velocity could exceed 0.2 m/s, with the remaining zones having air velocity of not more than 0.1 m/s. Their research work showed the consistent results of high indoor thermal comfort level due to lower vertical temperature gradient.

Renewable and low-grade energy can be employed in radiant cooling systems to improve the energy efficiency. Cooling could be more efficient with independent temperature and humidity control [12]. However, for the radiant cooling system the main challenge is insufficient dehumidification capacity. For this reason, a radiant cooling system always works together with a fresh air system to meet the latent load and even part of sensible load [4,13,14]. Sui and Zhang [15] reported that the energy consumption of such a hybrid system decreased when the sensible load handled by the radiant terminal increased. To prevent the condensation of moisture on a radiant surface, the surface temperature of a radiant panel needs to be higher than the indoor dew point temperature. Based on this, the surface temperature of the radiant panel should be considered as a significant factor for the stability of the system. Ge et al. [16] indicated that the pre-dehumidification time is critical to prevent condensation on the radiant cooling surface. Three neural network models were established to predict the risk of condensation and the optimal pre-dehumidification time in radiant cooling system. The program gave the value of 30 min as an optimal pre-dehumidification time for the simulated building in Hong Kong. Shou and He [17] used the index of “dehumidification capacity per unit mass of fresh air” to determine suitability of a building to use radiant cooling system. It was shown that when a fresh air system was employed to handle all latent cooling loads, a radiant cooling system could be used in public buildings, such as meeting rooms, markets and offices. Song et al. [18] proposed a radiant floor cooling system assisted by dehumidifying ventilation. The simulation results showed that the proposed system was able to prevent the condensation of moisture on the floor surface. Beside, responsiveness of the control system for indoor load changing was improved.

Based on previous research done, heat transfer between radiant panel and the ambient, as well as condensation on the radiant panels have been reported as crucial aspects affecting radiant cooling systems. This paper focuses on the parameters influencing heat transfer performance of the radiant cooling system. It also analyses the moisture condensation on radiant cooling panel has also been analyzed. In addition, analytical interactions between heat transfer and condensation effects have been outlined. In this research, standard temperature and humidity of 26 °C and 60% RH, respectively were widely chosen due to the application condition of the radiant cooling system.

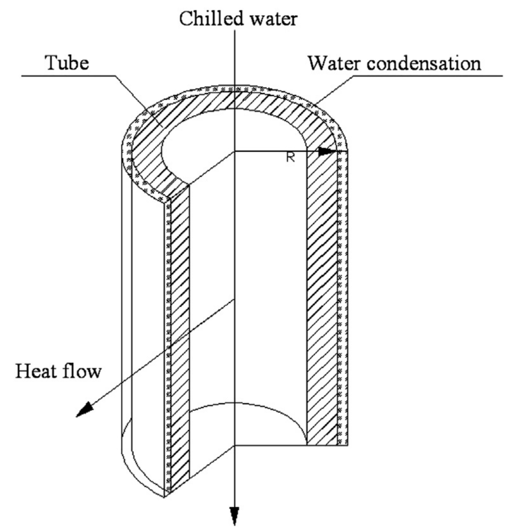

Fig. 1. Schematic diagram of the radiant cooling system.

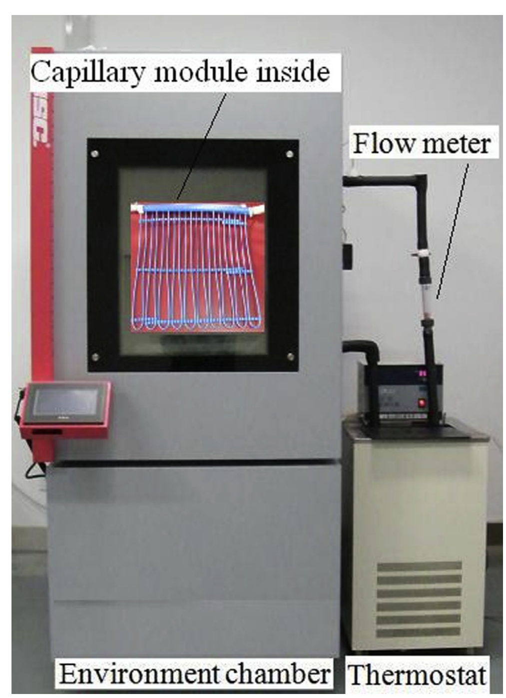

Fig. 2. Experimental system.