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Research Paper

Experimental research on a double-layer radiant floor system with phase change material under heating mode

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HIGHLIGHTS

- A new double-layer radiant floor system with phase change material is developed.
- An experimental system was built and the temperature field of the system was studied.
- The experimental results show that the new system can meet the thermal need of users.
- Compared to box A, box B has higher air temperature and air temperature change.
- The increase in supplied water temperature will decrease the thermal storage time.

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ABSTRACT

In this paper, a new double-layer radiant floor system with phase change material (organics) is proposed, which can store thermal or cold energy in the off-peak period and use it in the peak period. The new system can work in both summer and winter, and the system does not need an additional refrigeration system, which only works in summer to supply cold air. By this way, the initial cost of the system will be decreased. An experimental setup was developed to study the performance of the new system under heating mode. The experimental results show that the double-layer radiant floor system with phase change material can meet the thermal need of users under heating mode. As the temperature rise in the thermal storage phase change material happens in the thermal storage process, the energy consumption of the system is lowered during thermal storage process. Under the same condition, experimental box B has the higher air temperature, but the air temperature change in box B is also bigger than box A. The floor temperature in box A in the heat release process changes little, which has a temperature difference of 2 °C during the whole heat release process.

1. Introduction

The electrical power used in buildings varies greatly during day and night, which causes power companies in many countries to have difficulties in keeping up with the demand in peak periods. Therefore, it is meaningful to look for ways to shift the electrical consumption from the peak period to the off-peak period. At present, phase change materials (PCMs) are recognized as one of the effective ways [1–3].

With the development of social economy and the improvement of personal living standards, the use of air-conditioners is widespread in the society. Among all air conditioning technologies, the radiant floor heating system has been widely used in many countries [4–8]. The radiant floor heating system is a low-temperature heating system that can make efficient use of building space and needs no requirements for cleaning. The radiant floor heating system does not produce noise, cause drafts or use ducts. Moreover, the system provides uniform temperature distribution, which is suitable for improving personal living standards.

However, the radiant floor heating system usually uses electric power among the whole working time, which is harmful to the energy power supplying and the environment. Therefore, the radiant floor heating system with phase change material has been studied by many researchers in recent years [9–14]. Mazo et al. [11] described a model developed to simulate a radiant floor system with PCM in simple building types. The PCM radiant floor model was based on a one-dimensional finite difference scheme where the effective capacity method is used for PCM simulation. Ansuini et al. [12] reported the development of a lightweight piped radiant floor prototype with an integrated PCM layer aimed at buffering internal gains at constant temperature during summer cooling regimes without affecting its winter warming capacity. Zhou and He [13]

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investigated the performance of a low-temperature radiant floor heating system with different heat storage materials (sand and phase change material) and heating pipes (polyethylene coils and capillary mat) in the floor structure of a test room experimentally. The results indicated the advantages of using a PCM–capillary mat combination for low-temperature floor panel typical of solar hot-water heating systems.

The radiant floor heating system combined with phase change material can store thermal energy in the phase change material by using valley electricity at night, and the difference between the peak and valley power load will be smaller. However, the system can only work in winter and will be idle in summer. As a result, the maintenance consumption of the system will be improved and people need an additional refrigeration system, which only works in summer to supply cold air. By this way, the initial cost and operational cost will be improved. In order to reduce the cost of the radiant floor heating system combined with phase change material, Jin and Zhang [14] developed a new double layer phase change material (PCM) floor, which can work for people in both winter and summer. The system is used to store thermal or cold energy in the off-peak period and release them in the peak period. Compared to the radiant floor without PCM, the energy released by the floor with PCM in the peak period will be increased by 41.1% and 37.9% during heating and cooling when the heat of fusion of PCM is 150 kJ/kg.

In order to improve the heat transfer performance of the double layer phase change material (PCM) floor, a new double-layer radiant floor system with phase change material is proposed in this paper. In this system, the heat exchange pipes are placed in the thermal storage phase change material and the cold storage phase change material directly. In this paper, an experimental investigation on the performance of the double-layer radiant floor system with phase change material under heating mode is reported. The thermal storage performance and heat release characteristic of the new system are analyzed. Moreover, the energy consumption in the thermal storage process of the new system is studied. The results will not only support the theoretical analysis but also inspire new ways to optimize the performance of radiant floor systems with phase change material.

2. Double-layer radiant floor system with phase change material

In order to improve the heat transfer performance of the double layer phase change material (PCM) floor, a new double-layer radiant floor system with phase change material is proposed. The structure of the new system is shown in Fig. 1. The new system consisted of a floor, leveling layer, thermal storage phase change material, cold storage phase change material, reflecting film, insulation layer, building, hot water pipe and cold water pipe. The hot water pipe is filled in the thermal storage phase change material, and the cold water pipe is filled in the cold storage phase change material. Under different climate conditions, the new system has two operational modes.

1. Heating mode. Under this operational mode, the new system uses cheap electric power at night to heat the water. The hot water flows into the hot water pipe and heats the thermal storage phase change material. By this way, the temperature of the thermal storage phase change material is improved and the thermal energy is stored. In the daytime, when people need a thermal environment, the thermal storage phase change material will release the thermal energy to heat the air in the room. As a result, the temperature of the building room will be maintained in the suitable zone. Under this operational mode, the thermal energy storage process happens at night and the heat release process happens in the daytime.

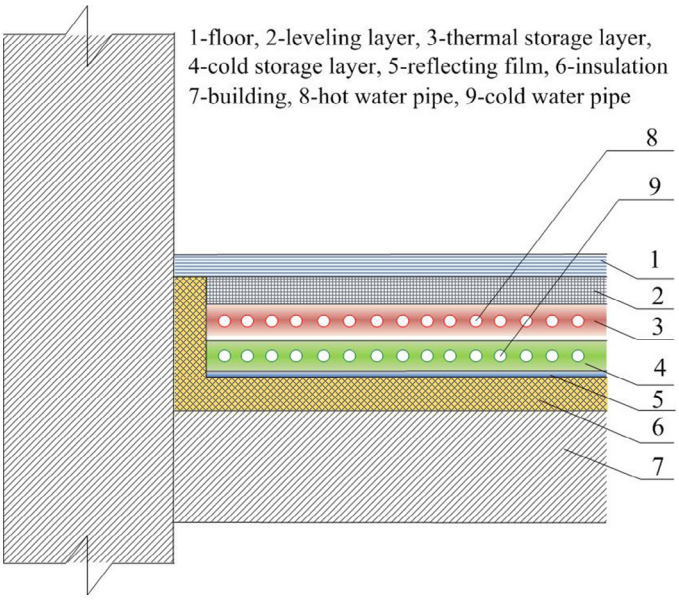

Fig. 1. The structure of double-layer radiant floor system with phase change material.

2. Cooling mode. Under this operational mode, the new system uses cheap electric power at night to cool the water. The cold water flows into the cold water pipe and cools the cold storage phase change material. By this way, the temperature of the cold storage phase change material is decreased and the cold energy is stored. In the daytime, when people need a cold environment, the cold storage phase change material will release the cold energy to cool the air in the building. As a result, the temperature of the building room will be maintained in the suitable zone. Under this operational mode, the cold energy storage process happens at night and the cold energy release process happens in the daytime.

The new system has many advantages. Firstly, the new system can use cheap electric power at night to heat or cool water, and stores the thermal energy or cold energy which should be used in the daytime. By this way, the cost of the system will be decreased. Secondly, the hot water pipe is filled in the thermal storage phase change material, and the cold water pipe is filled in the cold storage phase change material. By this way, the heat transfer resistance of the system will be decreased and the heat transfer efficiency of the system will be improved. Finally, the system can work in both summer and winter, and the system does not need an additional refrigeration system, which only works in summer to supply cold air. By this way, the initial cost of the system will be decreased.

3. Experiment setup

3.1. Experimental material

The phase change energy storage material in the experimental system is the organic fatty acid. The specific parameters of the thermal and cold storage phase change materials are shown in Table 1.

3.2. Experimental system

In the experiment, two different experimental boxes (shown in Fig. 2) were established to investigate the effect of different floor structures on the performance of the double-layer radiant floor system with phase change material. The two experimental boxes were built in a temperature and humidity control room. By this way,