Study on thermal performance of prefabricated thin phase change heating floor

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Abstract. A kind of prefabricated thin phase change heating floor was prepared by adding the shape-stabilized phase change material (PCM) into the prefabricated positioning plate, the thermal performance of phase change flooring at different average temperature of supply and return water was tested. The numerical simulation is carried out by using ANSYS software. The variation law and fitting relationship of surface temperature and heat flux with different average temperature of supply and return water were obtained. By comparing the experimental and simulated values, the error rate and the average correction factor were calculated.

1. Introduction

In recent years, building energy efficiency has become a hot topic in research. Combining phase change material and building envelope can improve indoor thermal comfort while saving energy. A large of domestic and foreign researchers have devoted to adding phase-change materials to the envelope, and the heat transfer process was compared by numerical simulation and experimental test.

Isabel Cerón et al. selected paraffin paraffins with phase change temperature of 20 °C as phase change materials, made phase change compound floor, and carried out the experimental test and numerical simulation of the composite floor [1]. L. Royon and L. Karim et al. installed the cylindrical cavity with PCM on the ground and the ceiling. Under the same boundary conditions, the ratio of PCM in the cylindrical cavity was studied by numerical simulation and experimental method [2]. Laurent, Royon and Laurie Karima et al. added the composite phase change materials containing 85% paraffin to the hollow concrete floor, and studied the optimal mass fraction of phase change material by experiment and simulation[3]. Javier Mazo and Monica Delgado et al. established the PCM floor radiation model based on finite difference scheme, and simulated two-dimensional heat transfer in the floor radiating plate[4]. Yan Quanying et al. established the model of phase change room and ordinary room, and simulated the changes of temperature and heat flow of the wall in typical meteorological year room by using ANSYS numerical simulation[5]. Feng Guohui et al. chose chemical stable capric acid as phase change material. The two-dimensional heat transfer model of the phase-change floor has been established. The finite element software ANSYS has been used to simulate the process of heat storage and release of the phase-change floor [6].

This paper established a new type of prefabricated thin phase change floor radiant heating system, and the heat transfer process of the system at different supply and return water temperature was compared and analyzed respectively by the methods of experiment and simulation. It is concluded that the change regulation of floor surface temperature and heat flux with the temperature of supply and
return water. And the average correction factor is obtained by modifying the simulated values with the experimental values.

2. Experimental study on prefabricated thin phase change heating floor

2.1. Experimental system and experimental conditions

Experimental room is located at 306 floor radiation heating laboratory, No.2 building, Beijing University of Engineering and Architecture, north, and the room size is 6m × 2.8m × 2.6m (length × width × height). The room on the upstairs, downstairs and east side is equipped with ordinary radiators for heating, and the toilet is on the west. The east wall and the west wall of the room are interior walls. The north wall has a size of 1.74m × 1.62m single steel window, and directly contact with the outside environmental. The south wall is a single-layer glass door, which separates the experiment room from the operation. The experiment room is divided into two areas: north and south. The ordinary prefabricated thin floor is laid on the north side of the window, and the prefabricated thin floor with the phase change material is laid on the other side.

The working process of the experimental system is as follows: the electric heating rod heats the distilled water to raise its temperature. The hot water passes through the Y-type filter and the water separator under the action of the booster pump. The distilled water enters the floor loop under the function of the water separator. Then it enters the water collector after the ground cooling, and flows through the Y-type filter back to the open water tank, which keeps repeating. The specific flow chart is shown in Figure 1.

![Figure 1. Schematic diagram of the experimental system.](image)

1. Power supply  2. transformer  3. Electric heating rod  4. Open water tank  5. Ball valve
6. Booster pump  7. Y type filter  8. Pressure gauge  9. Platinum resistance thermocouple
10. Water separator  11. Water collector

Previous studies on the comparison and analysis of common floor and phase change floor have shown that the phase change floor has incomparable advantages over ordinary floor. On this basis, the experimental conditions are as follows: the average temperature was 35 °C, 40 °C, 45 °C, 50 °C, 55 °C and the temperature difference between water supply and return water was 5 °C. The experiment was respectively carried out for 3 hours heating - 8 hours heating - stop heating for 8 hours under five conditions. Assumed that phase change floor model initial temperature was 20 °C, and the numerical simulation of the above five working conditions was carried out. And then the results were compared with the measured ones. The heating pipe adopted "double back shape" laying mode. The distance between the tubes was 150mm, and the diameter was 14mm.

2.2. Experimental instruments and equipment

The instruments and equipment used in this test are shown in Table 1.
### Table 1. Experimental instruments and equipment.

| Serial number | Name                          | Model number       | Accuracy and range               | Effect                                      |
|---------------|-------------------------------|--------------------|----------------------------------|---------------------------------------------|
| 1             | Circulating water pump        | 15WBX0.6-10        | 0.6 m³/h                        | Provide cyclic power                        |
| 2             | Transformer                    | TDGC2-2            | 0.1 V                           | Adjust the supply and return water temperature |
| 3             | Electromagnetic flowmeter      | 7ME5038-2AA12-1AA0 | 0.0001 m³/h                    | Test system water flow                      |
| 4             | Platinum resistance temperature sensor | PT100 | 0.1 °C                         | Test the supply and return water temperature |
| 5             | Infrared thermal imager        | TH9100             | 0 ~ 250 °C                      | Find the surface of the floor and the tube between the tube position |
| 6             | Agilent data collection meter  | 34970A             | -100 ~ 400 °C                   | Record the temperature of the measuring point |
| 7             | Water break automatic control water distiller | DZ-20 | 0.02 m³/h                     | Make distilled water                        |
| 8             | Pressure gauge                 | MC03820348         | 0.001 MPa                       | Test system pressure                        |
| 9             | Multipoint heat flow meter     | HFM-215            | 10 ~ 3000 w/m²                  | Test the surface heat flux density of the floor |

2.3. Structure of prefabricated thin phase change heating floor

According to the previous research results of our group, the phase change materials (48# solid paraffin-Liquid Paraffin) and high density polyethylene were mixed by the ratio of 7:3 in steel container. And then put it in an electric furnace at a temperature of 140 °C. The heating time was set to 40 minutes. After heating, removed the phase change material and stired constantly with the glass rod. When there was no obvious liquid flow in the mixture of the container, the steel container was heated in the electric furnace and stired repeatedly until the shaped phase change materials were mixed evenly. In the end, the mixed uniform shaped phase change materials were poured into the pre-made positioning plate channe. After natural cooling and solidification, the positioning plate containing shape stabilized phase change materials was prepared. The concrete structure of floor layer is shown in Figure 2.

1. wood floor layer (10mm)
2. Heat conductive aluminum plate (0.5mm)
3. Shape stabilized phase change material layer (16.5mm)
4. PE-RT heating tube (14/10mm)
5. Positioning plate (21/4.5mm)
6. Polystyrene foam plastic sheet (20mm)
7. Floor (110mm)

**Figure 2.** Prefabricated thin and light phase change flow structure diagram.
2.4. Layout of experimental measuring points
The experimental system respectively divided the phase change floor and the ordinary floor into four regions. In each area, the temperature measurement points between the tube top and the tube were selected. The layout of the measuring points on the wall and window guard structure selected the face diagonal of the envelope structure. The distances from the ground were 0.15m, 0.45 m, 0.75 m, 1.05 m, 1.35 m, 1.65 m, 2 m, 2.60 m (roof). The multipoint heat flow meter had five measuring points, which were arranged in five positions: the east, the west, the south, the north and the middle of the testing floor. The measurement points of the downstairs room were arranged at the bottom of the common floor and the phase change floor, the indoor temperature measuring point downstairs was selected 0.75 m from the ground. A pressure measuring point and a temperature measuring point were arranged at the upstream of the water separator and downstream of the water collector. The layout of the indoor measuring points is shown in Figure 3.

![Figure 3 Distribution of measuring points in room model](image1)

3. Numerical simulation of prefabricated thin phase change floor
The mathematical model of prefabricated thin phase-change floor heating system was established, and the heat storage and heat release under different working conditions and different periods were simulated by ANSYS software. The changes of surface temperature and heat flux density were studied and the simulated values were compared with the experimental values. In order to facilitate calculation, the simulation process made the following assumptions: 1) The material of each layer was isotropic, and its physical parameters are constant; 2) The lower surface of the floor was insulated; 3) Ignored the contact thermal resistance of the material between the layers and the temperature drop along the pipe length; 4) The phase transition temperature of the shaped phase change material was constant; 5) Ignoring the radiation heat transfer in the air Angle was considered as pure thermal conduction process. The mathematical model is shown in Figure 4.

![Figure 4 Mathematical model](image2)
Surface on the floor:

\[-\lambda \frac{\partial t}{\partial n} \bigg|_{d_j} = \alpha_i (t_{d_j} - t_n) \quad (1)\]

Among them

\[\alpha_i = \frac{q_c + q_r}{t_{p_j} - t_n} = \frac{2.13 (t_{p_j} - t_n)^{31} + 4.98 \times 10^{-8} (T_{p_j}^4 - T_f^4)}{t_{p_j} - t_n} \quad (2)\]

In this equation: \(\lambda\) — Thermal Conductivity, W/(m•K); \(\alpha_i\) — Equivalent convective heat transfer coefficient W/(m²•K); \(t_{d_j}\) — Average surface temperature of floor, ºC; \(t_n\) — Average temperature of indoor air, ºC; \(t_{p_j}\) — Average temperature of heating surface, ºC; \(T_{p_j}\) — Open surface temperature of heating surface; \(T_f\) — Weighted average open temperature of non heating surface.

Two side boundary insulation of phase change floor model:

\[-\lambda \frac{\partial T}{\partial x} \bigg|_{x=0, x=0.15} = 0 \quad (3)\]

The inner wall of the water pipe is the first boundary condition: \(T_{nb} = T_{sh}(\tau)\)

4. Experimental results and simulation results are compared and analyzed

The initial temperature of the phase transition floor model is assumed to be 20 ºC. We added hot water with the average supply and return water temperature of 35 ºC, 40 ºC, 45 ºC, 50 ºC and 55 ºC to the hot water pipe and it was carried out for 3 hours heating - 8 hours heating - stop heating for 8 hours. ANSYS was used to simulate the heat storage and heat dissipation of phase change floor with the temperature difference of 5 ºC in 5 kinds of conditions during the 19 hours. And it was compared with the measured values. Experimental results and simulation results are shown in Figure 5 - Figure 9.

**Figure 5.** 35 ºC phase transition floor surface temperature and heat flow distribution.

**Figure 6.** 40 ºC phase transition floor surface temperature and heat flow distribution.
As can be seen from the above figure, the experimental value and the simulated value of the surface temperature and the surface heat flow are the same as the change of the time value regardless of the average temperature of the return water. For the floor surface temperature, the error rate of the experimental value and the simulated value is within 12.5%. The error rate of surface heat flow is within 15% except for individual points. During the heating phase, the measured floor surface temperature and the surface heat flow of the floor are more consistent with the simulation results. In the stable phase, the heat flow simulation value is larger than the experimental value and shows an upward trend, which shows the heat storage of the fixed phase change materials. During the cooling phase, the simulated heat flux decreases rapidly and eventually is lower than the experimental value. The simulated surface temperature of the floor is close to the experimental value.

5. Conclusions
(1) Through the experimental analysis and numerical simulation of the phase change floor under different working conditions, it is shown that the experimental value agrees well with the simulated value. The surface temperature error rate of phase change floor is less than 12.5%. The error rate of the heat flow is within 15%. And the simulation values and experimental values converge into a curve, and find that the simulation values is too large. The average correction coefficient of the calculated temperature and heat flow is respectively 0.954 and 0.863 in different working conditions.

(2) Due to the finite experimental condition, ANSYS software can simulate the heat transfer performance of the system under any operating conditions, so as to provide data support for actual engineering design.
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Reference
[1] Sabel Cerón and Javier Neila et al. 2011 Experimental Tile with Phase Change Materials (PCM) for Building Use [J] Energy and Building 43 1869-1874
[2] L. Royon and L. Karim et al. 2014 Optimization of PCM embedded in a floor panel developed for thermal management of the lightweight envelope of buildings [J] Energy and Buildings 82 385-390
[3] Laurent Royon and Laurie Karim et al. 2013 Thermal energy storage and release of a new component with PCM for integration in floors for thermal management of buildings [J] Energy and Buildings 63 29-35
[4] Javier Mazo and Monica Delgado Jose, et al. 2012 Modeling a radiant floor system with Phase Change Material (PCM) integrated into a building simulation tool: Analysis of a case study of a floor heating system coupled to a heat pump [J] Energy and Buildings 47 458-466
[5] YAN Quan-ying and WANG et al. Xiao 2015 Numerical simulation of heat transfer performance in passive phase change room [J] New Building Materials 4 22-25
[6] FENG Guo-hui and CUI Jie et al. 2012 Study on heat storage performance of phase change energy storage floor heating system [J] Journal of Shenyang Jianzhu University 28(3) 529-532