Numerical Simulation of Thermal Performance of Floor Radiant Heating System with Enclosed Phase Change Material

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Abstract: In the present paper, a kind of enclosed phase change material (PCM) used in solar and low-temperature hot water radiant floor heating is investigated. On the basis of obtaining the best performance of PCM properties, a new radiant heating structure of the energy storage floor is designed，which places heat pipes in the enclosed phase change material (PCM) layer, without concrete in it. The PCM thermal storage time is studied in relation to the floor surface temperature under different low-temperature hot water temperatures. With the method of enthalpy , the PCM thermal storage time is studied under different supply water temperatures, supply water flows, distances between water wipe in the floor construction, floor covers and insulation conditions.

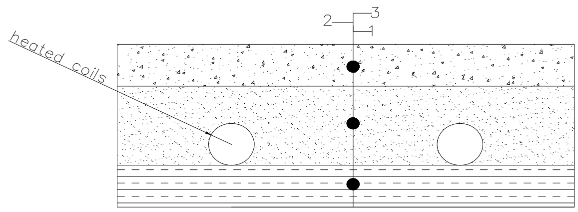
Key words: radiant floor heating； energy storage；PCM； enthalpy ； thermal storage time

1.INTRODUCTION

Phase change heat stored floor is an advanced heating technology which uses PCM absorbing latent heat and keeping its temperature nearly invariable when phase changes and it has high heat stored density. This technology well resolves energy supply-demand disagreement and thanks to its use of off-peak electricity and solar energy, it is one of the best ways of improving energy efficiency. Meanwhile, phase change heat stored floor can also control ambient temperature and improve the comfort indoor. Consequently, this technology is becoming a hotspot in the flied of architecture saving energy[1-4]. This paper represents the effects of factors on heat stored floor with inner heat source (water coils and electrical conduit) and thermal performance under three different boundary conditions.

2. MATHEMATICAL MODELING

The construction of heating floor with PCM and inner heat source was shown in Fig.1 and its thermo-physic parameters of heating floor materials was given in tab.1. The PCM chosen was a kind of hydra-salt whose phase change temperature is about 29□. To keep the PCM from leaking out when thawing and corroding the concrete, the PCM was packed. The heated coils were placed on the heat insulation and the packed PCM were around the heated coils on whose head was floor cover. When the coils heated, the heat was transported to the PCM in the floor and was stored. Then, it released to the room when needed.



1-heat insulation 2-PCM floor with heated coils

3- floor cover

Fig.1 Construction of heat stored floor

With the theory of phase change heat transmission, a theory model of the thermal performance was founded according to the mentioned above heat stored floor. As to the study of the phase change energy storage systems, it is often used enthalpy and specific heat. Specific heat is directly based on temperature, but it needs the solid-liquid interface being followed. Furthermore, it is usually used in PCM whose phase change occurs at a temperature point. Unlike Specific heat, Enthalpy is based on enthalpy and temperature, then with the relationship of the temperature and enthalpy in the energy equation, the temperature distribution will be obtained. The phase change of the shape-stabilized phase change material (PCM) often occurs in a wide temperature range rather than at a certain temperature point. The advantage of the enthalpy is that the solid-liquid interface should not be followed and the energy equation is suitable for solid, solid-liquid and liquid, which remarkably simplifies the simulation, therefore it is especially suitable for the multi-dimension models. To simply the simulation, the hypothesis was made as follows:

① heat transmission of the floor cover, packed PCM and the heat insulation was viewed as two-dimensional, the heat transmission along the coils length was neglected;

② the ambient of the heat coils was full of PCM;

③ neglect the effect of the liquid PCM's convection, the heat transmission was simplified as heat conduction;

④ the temperature indoor was equable;

⑤ the complex coefficient of heat transmission between the floor surface and the air indoor was supposed as constant.

Tab. 1 Thermo-physical parameters

	bamboo floor	Granite floor	PCM	heat insulation
density kg/m^3	746	820	1510	31
heat conduction coefficient W/(m·K)	lateral 0.8 longitudinal2.4	3.1	0.8	0.031
specific heat kJ/(kg·K)	2.431	2.800	solid1.43 liquid2.31	1340
phase temp. □			29	
phase latent heat kJ/kg			188	
phase radius□			1	

This paper took the circular boundary formed by the PCMs and coils into account and the discrete equation was separately established according to the first boundary condition (invariable wall temperature), the second boundary condition (invariable heat flow) and the third boundary condition (heat convection). The heat stored process can be considered to have finished when the last point in the PCM finishes its phase change. The grid units of the heat stored floor were shown as Fig.2. With enthalpy, the math description of the model mentioned above can be as follows:

$$\rho\frac{\partial H}{\partial \tau} = k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (1)$$

$$-k\frac{\partial T}{\partial y}\Big|_{y=\text{floor surface}} = h\left[T(y_{\text{floor surface}})-T_f\right] \quad (2)$$

Where, k---- the heat conduction coefficient of the material, W/(m·K); T_f--- the mean temperature of air indoor, □; H--Specific enthalpy, J/Kg; the relation of the temperature T and the Specific enthalpy H is as follows:

$$T = H/c_{ps} \qquad H < H_s$$

$$T = \frac{H+(T_m-\varepsilon)L/2\varepsilon}{c_{ps}+L/2\varepsilon} \qquad H_s \le H \le H_l$$

$$T = T_m + \varepsilon + \frac{H-H_l}{c_{pl}} \qquad H > H_l$$

Where, c_{ps} and c_{pl} —solid mean specific volume and liquid mean specific volume of the phase change material separately, J/(kg·K); ε — the half of the phase change temperature ΔT (the radius of the phase change); T_m---phase change temperature, □; L —the latent heat of the stable phase change material, J/kg; H_s and H_l —solid saturated Specific enthalpy and liquid saturated Specific enthalpy separately, J/kg. therefore

$$H_s = c_{ps}(T_m-\varepsilon), H_l = c_{ps}(T_m+\varepsilon)+L \quad (3)$$

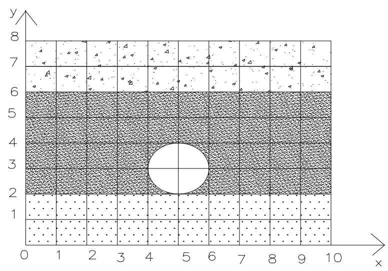


Fig.2 Model grid units of heat stored floor

3. NUMERICAL SIMULATION RESULTS AND DISCUSSIONS

It was necessary that the effect of the thermal stored medium in the heat stored floor with inner heat source under different boundary conditions was analyzed. Duo to the size of the heat coils being in the same grade of the PCM's dimensions, the circular boundary condition of the coils should be taken account into and the analysis of the three thermal boundary conditions was realistic. The boundary condition of the heat stored floor heated by electrical conduits was the second one(invariable heat flow) and heated by the water coils should be the third one(convection heat), which can be viewed as the first one (invariable wall temperature) when the water was at rest or the water flew very slowly.

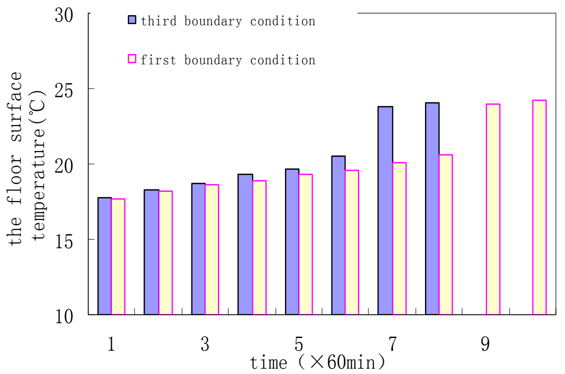


Fig.3 Relation of floor surface temperature and heat stored time under different boundary condition

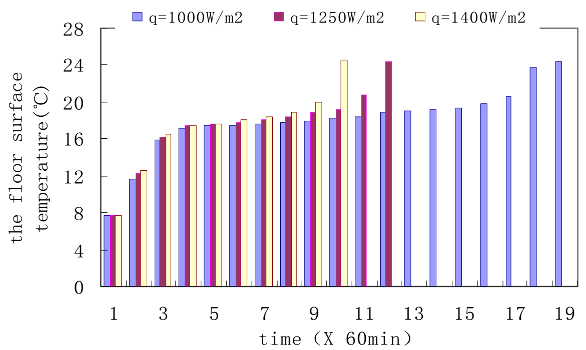


Fig.4 Relation of floor surface temperature and heat stored time under the variable heat flux

As to the water coils, the Fig.3 gave the heat stored time comparison when the temperatures of the thermal stored bamboo floor surfaces reached to the same point under the heat coils PEX(φ20×2), coil space 60mm, supply water temperature 55□, the temperature difference of the supply and return water temperature 6□, water flow 5L/min, heat loss percentage 10% and the heat stored medium under the first and the third boundary conditions respectively. As to the electrical conduit, Fig.4 shows the relation of the floor surface temperature changed with heat stored time when three different electric powers heated under the conditions mentioned above and the outside diameter (OD) of the electrical conduit being 20mm.

It can be seen from the outcome of the calculation that the heat stored time of the third boundary condition was less than the first one when the floor surface temperature reaching the same point. This manifested that the convection caused by the fluid's flow fastened the heat transmission which boosted the velocity of the heat transmission and shortened the time of heat stored. As to the different electrical heat conditions, the heat flux higher, the heat stored time less.

In this paper, the heat performance of the floor with heat source was simulated dynamically under two different floor covers, three different coil spaces and different heat supply conditions. All the alternated factors were seen in Tab.2.

Tab.2 Variable parameters

	variable factors	setting values
heating parameters of the system	supplying water temperature	51、53、55(□)
	temperature difference of the supplying and returning	4、6、8(□)
	supplying water flow	3、5、7 (l/min)
boundary parameters of heated coils	①constant temperature	$t_w=(t_g+t_h)/2$(□)
	②constant heat-flux density	q_w=1000、1250、1400 (W/m^2)
	③ constant heat coefficient and fluid temperature	h=10（W/m^2□） $t_f=(t_g+t_h)/2$ (□)
parameters of floor construction	material of the floor cover	bamboo floor granite floor
	space between coils	60、80、100(mm)
	downward heat loss	0、10%、15%

The Fig.5 gave the relation of floor surface temperatures of two different floor covers changing with heat stored time under supply water temperature 51□, the temperature difference of the supply and return water temperature 6□, water flow 5L/min, coil space 60mm, heat loss percentage 10%. The relation of granite floor surface temperatures varying with heat stored time under different supply and return temperatures and different coil spaces were given in Fig.6 and Fig.7.

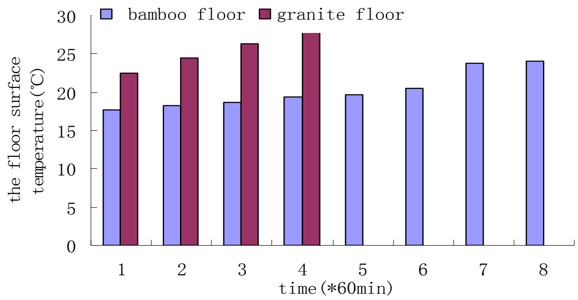


Fig.5 Relation of floor surface temperature and heat stored time under different floor covers

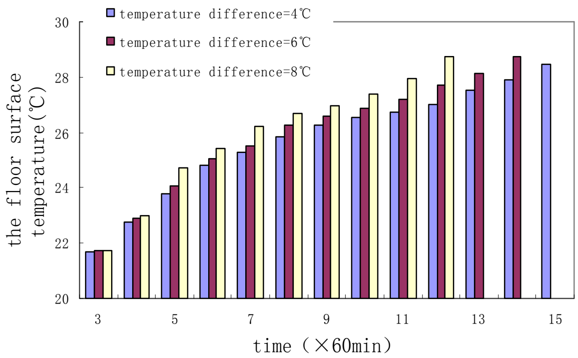


Fig.6 Relation of floor surface temperature and heat stored time under different supplying and returning temperature differences

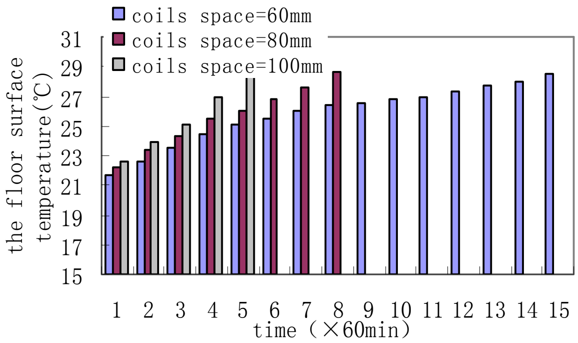


Fig.7 Relation of floor surface temperature and heat stored time under different coils spaces

4. CONCLUSIONS

It can be seen from the simulation that ①the heat stored time, when reaching the equal temperature point, was less when the heat conduction of the floor was better ② the heat stored time lengthened when the supply and return temperature difference decreased ③ the heat stored time was less when the coil space was less, however, the heat release time was less, which can't reach the heat required, so the coil space should meet the required PCM's heat stored. In a whole, the floor surface temperature varied smoothly during the heat stored time and this mean that the floor surface temperature didn't fluctuated remarkably during the heat stored and released time, which contributed to the comfort indoor.

The heat stored floor with heat source greatly contributed to the saving energy and it can adjust the structure of the energy consumption. Meanwhile, the heat stored floor can also temper the air indoor and improve the comfort indoor and the life quality. The improvement of its technology will obviously benefit our economic and nation.

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