Structure Optimization of a Floor Cooling and Heating System for Ground Source Heat Pump

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ABSTRACT

This paper aim at the demand of using ground-source heat pump as heating source presents an investigation on a new structure of radiant floor which meet demand of cooling and heating system base on the use of ground source heat pumps, the research shows that the new floor heating system could solve some existing problems about conventional wet and dry-floor structure and integration of stem-floor structure. The investigation indicated that the new-structure floor heating system could be more suitable for using the ground source heat pump system.

1. INTRODUCTION

With the global implementation of the strategy of sustainable development, the use of renewable energy source heat pump technology is more widely used in building heating. The heating water temperature of this heating technology is lower so that it demands the big heating equipment area. In this case, radiant floor heating method compared with other heating systems shows low energy consumption. There are still some problems to be solved which works in the universal application of the low-temperature hot water radiant floor heating systems.

This paper aimed at some existing problems about conventional wet and dry-floor structure and integration of stem-floor structure studied on the temperature and heat flux density distribution factors and their impact on the new floor structure by the finite element method and experiment.

2. MATHEMATICAL MODEL

View of the problems of current low-temperature hot water radiant floor for heating, we proposed an new structure of the program including the floor slab, the insulating layer, lower heat conduction film, the heating pipe, the upper heat conduction film and the surface decoration. It can solve the problem of the structure of the conventional wet floor and the conventional dry floor. It reduces the floor thickness and the load of the floor. The structure thickness is about 37.3 percent of the conventional low-temperature hot water wet floor and the unit area load is only 1.4 percent of the conventional low-temperature hot water wet floor. It is also easy to construct and maintenance and has a short construction period, a good mechanical properties and resistance on the system.

To study the new structure of the thermal properties, a mathematical model was built to calculate temperature and heat flux. The assumptions are as follows.

(1)Arbitrary section on the process is the two-dimensional thermal heat transfer process.

(2)The temperature change along the hot water flow is much smaller than cross the section, and the water temperature of the section is the same.

(3)Materials of all levels are isotropic.

(4)Materials of all levels contact with each other closely and ignore the contact resistance.

(5)The surface temperature of the heating wall is similar to the average temperature of the backwater.

The description of the steady-state thermal conductivity of the two-dimensional differential equation of the calculation unit is as follow

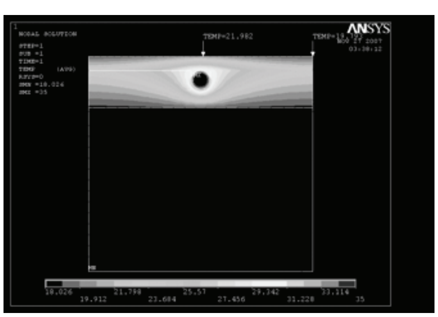
$$\frac{\partial t}{\partial \tau} = \frac{\lambda}{\rho c}\left[\frac{\partial^2 t}{\partial^2 x} + \frac{\partial^2 t}{\partial^2 y}\right] = 0 \tag{1}$$

3. SIMULATION RESULTS AND ANALYSIS

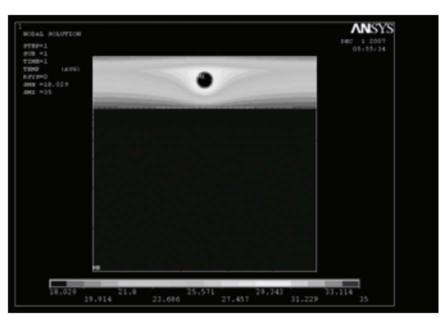
The new floor surface is the wooden floor, the distance is 150 mm between the two pipes, the room temperature is 18 ℃, the average water temperature is 35 ~ 50 ℃ and it has different film thickness. Based on all the conditions above, the temperature distribution and the floor heat dissipation were simulated

3.1The temperature of the ground construction

The temperature simulation results of the construction of the ground can shows as figure 1 to figure 4 and table 1

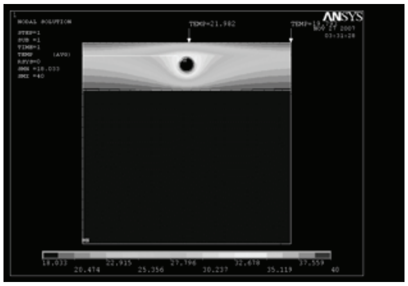


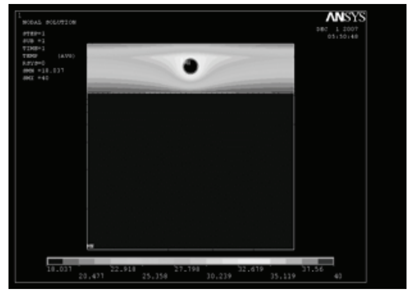
(a)Thermal film thickness is 0.1mm



(b)Thermal film thickness is 0.2mm

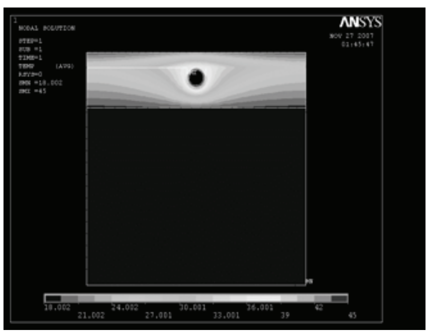
Figure 1 floor structure of the temperature distribution about water temperature of 35 ℃

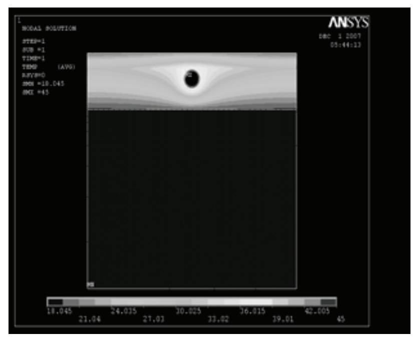




(a)Thermal film thickness is 0.1mm (b)Thermal film thickness is 0.2mm

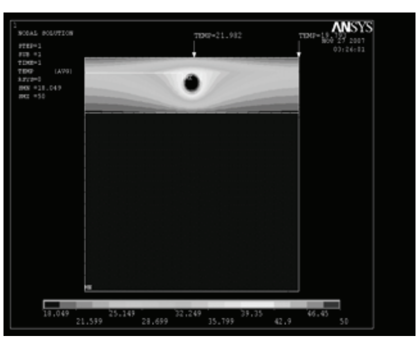
Figure 2 floor structure of the temperature distribution about water temperature of 40 ℃

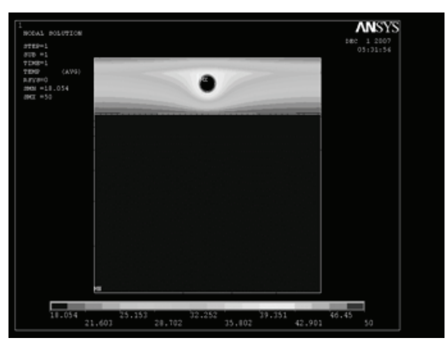




(a)Thermal film thickness is 0.1mm (b)Thermal film thickness is 0.2mm

Figure 3 floor structure of the temperature distribution about water temperature of 45 ℃





(a)Thermal film thickness is 0.1mm (b)Thermal film thickness is 0.2mm

Figure 4 floor structure of the temperature distribution about water temperature of 50 ℃

Table 1 Distribution of floor surface temperature

<table>
<tr><td colspan="4">heating distance is 150 mm
aluminum foil thickness is 0.1 mm
surface floor is wooden</td><td colspan="4">heating distance is 150 mm
aluminum foil thickness is 0.2 mm
surface floor is wooden</td></tr>
<tr><td>Room Temperature</td><td>Backwater Temperature</td><td colspan="2">Floor surface Temperature</td><td>Room Temperature</td><td>Backwater Temperature</td><td colspan="2">Floor surface Temperature</td></tr>
<tr><td>℃</td><td>℃</td><td>Maximum</td><td>Minimum</td><td>℃</td><td>℃</td><td>Maximum</td><td>Minimum</td></tr>
<tr><td rowspan="4">18</td><td>35</td><td>22.06</td><td>21.13</td><td rowspan="4">18</td><td>35</td><td>22.46</td><td>21.58</td></tr>
<tr><td>40</td><td>23.25</td><td>21.45</td><td>40</td><td>23.19</td><td>22.04</td></tr>
<tr><td>45</td><td>23.98</td><td>21.79</td><td>45</td><td>23.91</td><td>22.51</td></tr>
<tr><td>50</td><td>24.72</td><td>22.13</td><td>50</td><td>24.64</td><td>22.97</td></tr>
</table>

The simulation results indicated that the thermal film is more thicker when the floor surface distribution is more uniform and the floor surface minimum and maximum temperature difference is smaller. It can raise the uniformity of the floor surface and internal temperature distribution effectively. The water temperature impact on the floor temperature uniformity is not obvious, but it has significant impact on the floor surface temperature. The average temperature of the floor surface is higher with the water temperature rises. The maximum temperature is in line with the norms floor heating floor surface temperature requirements.

3.2 Floor surface heat flux

The simulation results of floor surface heat flux can be seen in Table 2

Table 2 the heat dissipation of unit area about PB pipe w/m^2 (ground floor for wood floors)

Backwater temperature	Room temperature	heating distance is 150 mm aluminum foil thickness is0.1 mm	heating distance is 150 mm aluminum foil thickness is 0.2 mm
℃	℃	w/m^2	w/m^2
35	18	34.08	38.11
40	18	42.83	45.43
45	18	48.31	52.59
50	18	55.96	59.88

The calculated results show that with the increase of the thickness of the thermal conductivity, the heat release of the floor surface increase apparently. So the thermal conductivity can efficiently increase the heat release of the floor surface. With the water temperature increased the heat flux also increased.

4. EXPERIMENTTAL RESULTS

An experimental model room was established to search the thermal performance of the new-structure floor heating system. It mainly include the temperature distribution of the indoor air, the temperature distribution of structural layer about the floor heating system, and heat flux. The model room is a normal reinforced concrete structure room which faces to the north and with the size of 5.99m×2.75m×2.6m,the spacing of the heating pipe is 150mm,and the thickness of the film of heat conduction is 0.1mm.

Using the thermocouples, we measured the temperature of every spot in the floor heating laboratory ,using Tsinghua tongfang RH-LOG ,we measured the temperature of indoor, adjacent room ,and use multiple points heat flow meters to measure the heat flux and temperature of the floor surface and exterior wall.

4.1 The air temperature of indoor

When the temperatures of supply and return water are 35℃、40℃、45℃ and 50℃ respectively, the monitoring results of room temperature are showed in figure 5.

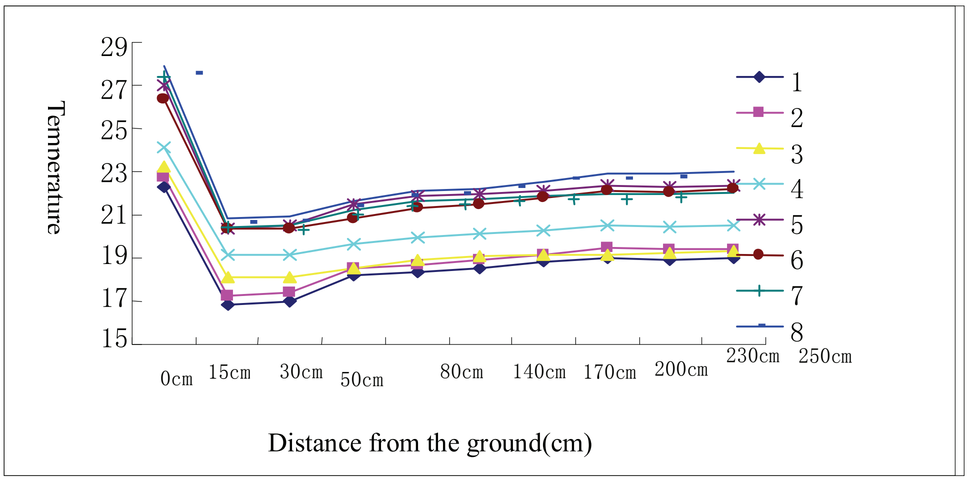


Figure 5 the vertical average temperature distribution in the room

From the measured results we got that the temperature of the floor surface and nearby is more higher, the vertical temperature distribution in the room is uniform, which reflects the feature of temperature distribution in the room that foot is cool and head is warm.

4.2 The temperature of floor surface

The temperature of floor surface shows in table 3.

Table 3 the temperature of floor surface

Water temperature	temperature difference	average indoor temperature t_{n1}	outdoor mean air temperature t_w	average floor surface temperature t_b	floor surface temperature		temperature difference △t
					Highest	Lowest	
℃	℃	℃	℃	℃	℃	℃	℃
35	5	18.31	3.42	22.32	23.37	21.20	2.17
	10	18.69	3.82	22.79	24.04	21.31	2.73
40	5	18.84	9.75	23.26	24.52	21.93	2.59
	10	19.96	10.12	24.16	25.53	22.72	2.81
45	5	21.70	7.97	27.04	28.04	25.54	2.84
	10	21.40	9.01	26.39	28.16	24.62	3.53
50	5	21.51	8.88	27.42	29.24	26.00	3.24
	10	22.13	8.78	27.90	29.95	26.21	3.73

The experimental results indicated that the temperature of floor surface increased with water supply temperature, also the maximum and the minimum temperature of floor surface increased with water supply temperature.when the water supply temperature is 50/40℃, the difference of the maximum and the minimum temperature of traditional structure floor is 4℃, while on the same condition, the difference of new-structure floor is 3.53℃,which means that the uniformity of temperature distribution is better than traditional construction[3].

4.3 The heat flux of the floor surface

The experimental datas about heat flux of the floor surface are showed in table 4 The results show that the heat flux gradually increases with the increase of the water temperature, and at the same water temperature, backwater temperature difference which impacts on the heat flux is not obvious.

Table 5 the heat flux of the floor surface

Water temperature	temperature difference	average indoor temperature	floor surface temperature	Upward heat flux
℃	℃	℃	℃	w/m^2
35	5	18.31	22.32	38.09
	10	18.69	22.79	37.93
40	5	18.84	23.26	45.24
	10	19.96	24.16	43.2
45	5	21.7	27.04	53.12
	10	21.4	26.39	52.43
50	5	21.51	27.42	62.01
	10	22.13	27.9	63.24

5. NUMERICAL AND EXPERIMENTAL RESULTS COMPARISON

Simulation and experimental results contrast under the same construction and condition is as table 5.

Table 5 numerical simulation and experimental results contrast

Water temperature	floor surface temperature			Floor surface heat flux		
	Experiment	Numerical Solution	Error	Experiment	Numerical Solution	Error
℃	℃		%	w/m^2		%
35	22.56	19.59	13.16	38.45	34.63	9.93
40	23.71	22.14	6.62	42.87	40.96	4.46
45	26.72	26.06	2.47	52.12	47.06	9.71
50	27.66	26.85	2.93	60.24	53.09	11.87

From the table we can find that, when the thickness of heat conduction film is 0.1mm, experimental data is more larger than numerical solution,and the maximum error of floor surface temperature is 13.16%,the maximum of heat flux is 11.87%,which mainly comes from the simplify of the theoretical Solving, experimental conditions, measurement error,and so on. Correcting the numerical simulation value according to the heat flux, when the thickness of heat conduction film is 0.1mm,and water temperature is 35~50℃, heat release of the floor surface can reach to 38.45 w/m^2 ~ 56.67 w/m^2. From the theory we can see that when the thickness of heat conduction film is 0.2mm,and water temperature is 35~50℃, heat release of the floor surface can reach to 39.38 w/m^2 ~ 59.78 w/m^2.

6. CONCLUSIONS

Based on the study on the temperature and heat flux density distribution factors and their impact on the new floor structure with the finite element method and experiment, the following conclusions can obtained.

(1) The new floor heating system has the advantages compared with the conventional wet and dry structure. It reduces the floor thickness and the load of the floor. The structure thickness is about 37.3 percent of the conventional low-temperature hot water wet floor and the unit area load is only 1.4 percent of the conventional low-temperature hot water wet floor. It is easy to construct and maintenance and it has a short construction period, a good mechanical properties and resistance on the system.

(2) The surface temperature distribution uniformity of the construction of the new floor heating is better than that of the traditional floor heating system. Thermal film and its film thickness have an important role to improve the uniformity of surface temperature distribution. Thicker the thermal film is, more better the uniformity of surface temperature distribution.

(3) When using ground source heat pump as the heat source with water supply and backwater temperature at the range between 35~50℃, the floor surface heat release of the new-structure can reach 38.09 w/m^2~ 63.24w/m^2. Besides, the film of heat conduction and it's thickness play an important role on improving heat flux of the floor surface, the thicker of the heat conduction film, the stronger of the heat dissipating is, and the proportion of downward heat transfer is smaller. Thus, it's a more suitable heating form that using ground source heat pump as heat resource.

REFERENCES

[1] Jiang Yi,2006, trends and focus of China's energy-saving building energy consumption, Green building special,vol.2006.7,P.10-15.

[2] Song, Bo ,2004, the way of the surface heating projects, the published papers of HVAC cooling of the 2004 academic symposium, vol. 2004 (8),p. 5-8.

[3] Zhang Ximin, Ren Zepei, Mei Feiming,1993,Heat transfer (third edition),Beijing: China Building Industry Press.

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