Analysis and Study of the Effect of the Direct Floor Radiant Heating System of the Air Source Heat Pump at Heating Working Conditions

Kun-ru Ma[1] , Na-na Hou[2]* , Xin Wang[3] and Xing-guang Wang[4],Yuefen Gao[5]

[1,2,3,4] *Department of Civil Engineering*, Hebei University of Science and Technology, Shijiazhuang, Hebei,050000, China
[5]North China Electric Power University 619 Yonghua Street Baoding,071003,China

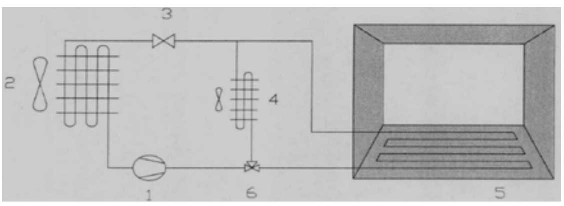
***Abstract* — This paper is established by the physical model and mathematical model of the direct floor radiant heating system of the air source heat pump system which are determined by two-dimensional heat conduction differential equation and boundary conditions, simulate and calculate the new system heating working conditions by FLUENT software. Then it summarizes the relationships of floor surface heat flow density and the influence factors: pipe diameter, pipe spacing, HTM temperature, indoor temperature, and floor surface materials,etc. The reliable quantitative basis for the practical application of engineering of the new system can be provided in terms of design, construction and operating maintenance.**

Keywords - Air source heat pump ; Floor radiation ; Heat flow density; Pipe diameter and pipe spacing; HTM tem-perature; indoor temperature; Floor surface materials; Energy –saving

I. INTRODUCTION

Since energy crisis broke out in the 1980s,there is an increasing attention on development of new energy and the degree of utilization[1]. According to this concern, energy and environmental issues have become the major bottleneck of the sustainable development of the world economy. Therefore both energy saving and emission reduction have been considered as an initial proposition in human survival and development, namely the urgent need for development of green, low-carbon, and sustainable energy.

For instance, air source heat pump with the advantage of environmental protection, energy-saving, stabilization, and reliability has been widely applied in heat ventilation air conditioning field. Compared to ordinary energy. Low temperature radiate floor heating technology has superiority on efficient energy-saving and low carbon environmental protection. Due to the advantage of cleaning, safe, and easy to calculate, it has been used maturely in engineering technology[2,4].



1-compressor 2-evaporator
3-electronic expansion valve 4-fan coil
5-radiant floor heating 6-triple valve

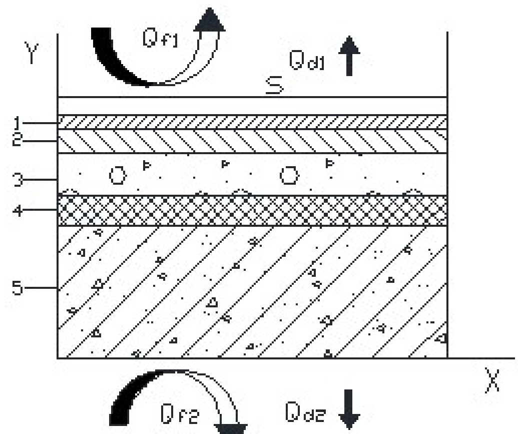
Fig.1 The Schematic Figure of the Direct Floor Radiant Heating System of Air Source Heat Pump

At present, there is rare study on new system of direct floor radiant heating of air source heat pump. The air source heat pump system is the heat source of low temperature floor radiant heating, and the heating medium heats the floor directly, the system schematic is shown in Fig.1.

II. ESTABLISHMENT OF THE MODEL

A. The Physical Mode

The floor layer structures show that decorative layer and screed-coat have direct contact with room air. Besides the function of smoothing surface for laying wood floor, screed-coat also has an impact on splicing face brick and stone.



1-surfacing 2-screed-coat
3-packing layer 4-insulating layer

Fig.2 The Floor Layer Structures and the Exterior Heat Transfer Conditions

The heating equipment are paved in the packing layer which includes the effects on protecting heating equipment and informing ground temperature. Then, insulating layer is mainly used to block heat transfer and reduce the feeble heat consumption. In addition, the floor layer which plays the role of load-bearing is the main structure of the building.

The simulation is about two-dimensional steady-state heat transfer of floor radiant heat, and the heat source is assumed to be air source heat pump. The buried pipe in floor structure layer is the condenser of air source heat pump. Due to the condensing phase transformation, the heat medium in coil transfers the heat to floor immediately. Through radiant heat transfer and heat convection of the floor surface which is served as thermal radiation surface, the heat is emitted into the room[5,7].

In view of the analysis and study of the new system floor heat transfer, problems of the system are caused by different pipe diameter, pipe spacing and floor surface materials. The floor layer structures and the exterior heat transfer conditions are shown in Fig.2.According to the literature[8].The general situation of physical model is shown in Table I.

TABLE I. THE GENERAL SITUATION OF PHYSICS MODEL

Type	Material	Value（mm）	Density（kg/m^3）	Specific heat capacity（J/(kg·K)）	Thermal conductivity（W/(m·K)）
Floor surface	Ceramic tile	10	2700	840	1.1
	Marble	10	2800	920	2.91
	wood（pine）	10	500	2510	0.14
Screed-coat	Cement mortar	20	1800	1050	0.93
Packing layer	Pisolite concrete	30	2100	920	1.28
Insulating layer	polystyrene	20	30	1380	0.047
Floor layer	Reinforced concrete	100	2500	920	1.74
Copper pipe diameter（mm）：5、7、9			Pipe spacing（mm）：80、100、120、140		
Indoor temperature（℃）：16、18、20、22			HTM temperature（℃）：35、40、45		

B. Mathematical Model

Heat conduction of floor structure layer is a complex three-dimensional thermal conductive process. This paper simplified the process of a two-dimensional thermal conductive issue, the minimum heat transfer calculation unit is shown in Fig.3 [9,11].

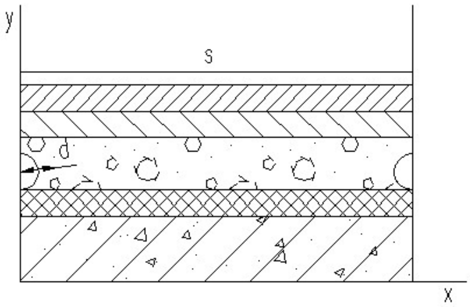


Fig.3 The Minimum Heat Transfer Calculation Unit

The Simulation calculation is about heat transfer unit between two half-pipes, the analysis method is the finite volume method. Through the differential equation of two-dimensional steady-state heat conduction and setting up boundary conditions, obtain a structural temperature field and a heat flow field[12]. The two-dimensional steady-state heat conduction differential equation of the minimum heat transfer calculation unit:

$$\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}=0 \quad (1)$$

Boundary conditions are as follows:

(1)the temperature field of the minimum heat transfer calculation unit is a symmetry, so the two boundary Parallels to the shaft are considered approximately adiabatic.

$$\frac{\partial t}{\partial x}\Big|_{x=0,\ x=s}=0 \quad (2)$$

(2)Ignoring the thermal resistance of copper pipe. heat transfer is well good, and the pipe wall has a good contact with heat medium, the pipe wall temperature is same to the heat medium temperature.

$$t_g=t_s \quad (3)$$

DOI 10.5013/IJSSST.a.17.28.04

ISSN: 1473-804x online, 1473-8031 print

Where, t_g is the pipe wall temperature; t_s is the heat medium temperature.

(3)we regard the heat transfer of floor surface boundary conditions as a combination. Since the conditions are affected by radiation heat transfer and convection heat transfer, it is treated as the second boundary condition [13].Using the formulation stated by Dr.Birol I·Kilkis for calculating.

$$q = q_d + q_f = \alpha_d(t_b - t_n) + \alpha_f(t_b - t_p) \quad (4)$$

Where, q is the heat flow density of floor surface; qd is the heat flow density of heat convection in floor surface; q_f is the heat flow density of radiant heat transfer in floor surface; α_d is the heat convection coefficient of floor surface; α_f is the radiant heat transfer coefficient of floor surface; t_b is the temperature of floor surface; n is the indoor design temperature; t_p is the average radiant temperature of non heating surface.

Heat convection coefficient is related to above sea level and dimensions of internal space[14].

$$\alpha_d = 2.67F_1\left(1 - 2.22\cdot 10^{-5}\cdot h\right)^{2.627}(t_b - t_n)^{0.25} \quad (5)$$

$$F_1 = \left(4.96 / D_{eq}\right)^{0.08} \quad (6)$$

$$D_{eq} = (4A_r / L_r) \quad (7)$$

$$\alpha_f = r\cdot F_r \cdot \sigma \quad (8)$$

$$r = 4\left[(t_{b1} + 273)/2 + (t_{p1} + 273)/2\right]^3 \quad (9)$$

Where h is height above sea level, and the altitude of shijiazhuang in the paper is 81M; D_{eq} is the equivalent diameter of floor surface; Ar is the floor area; Lr is the floor circumference; Fr is the simplified radiation exchange coefficient, when $A_p / A_u \le 0.30$, $F_r = \varepsilon$; A_p is the pipe laying area; σ is the black body radiation constant; ε is the radiant emissivity, in general, the radiant coefficient of the metal or the metal non reflective surface with oil is about 0.9; A_u is the total area of upper heating surface.

According to the literature, the determination of the average temperature of the non heating surface requires a complex numerical calculation method[15].So the paper will deviate from the focus of the research, and the conclusion is only suitable for the common residential units for5.7M×3.9M×2.8M (length × width × height) in China.

Therefore, this paper will not use the relevant numerical calculation method, but adopt the general conclusions of the literature[13].

For a normal room with door and window, it is considered that the difference between the average radiant temperature of the non heating surface and the indoor temperature is -20F.

The corresponding values are brought into the formula, hence the formula of the upper surface heat transfer is carried out.

$$q = -\lambda\frac{\partial t}{\partial y} = 2.67(t_b - t_n)^{1.25} + 2.04\times 10^{-7}\left(\frac{t_b + 273}{2} + \frac{t_n - 1.1 + 273}{2}\right)^3 (t_b - t_n + 1.1) \quad (11)$$

III. NUMERICAL SIMULATION, RESULTS AND DISCUSSION

This paper uses the finite volume method in order to make the calculation area into discretization, and generate the mesh. As the control equation is discretized on the grid. First of all, it is necessary to simulate, calculate, and adopt SIMLPE algorithm by using FLUENT software. Then, loading the UDF program code of custom function into the running FLUENT should be accomplished carefully. Finally, results has been output after calculating the coupling equation[16,18]. Therefore, this paper reaches to a conclusion on relationships among heat flow density of the floor surface and pipe surface, pipe diameter, HTM temperature, indoor temperature, and floor surface materials, shown in Fig.4 to Fig.10.

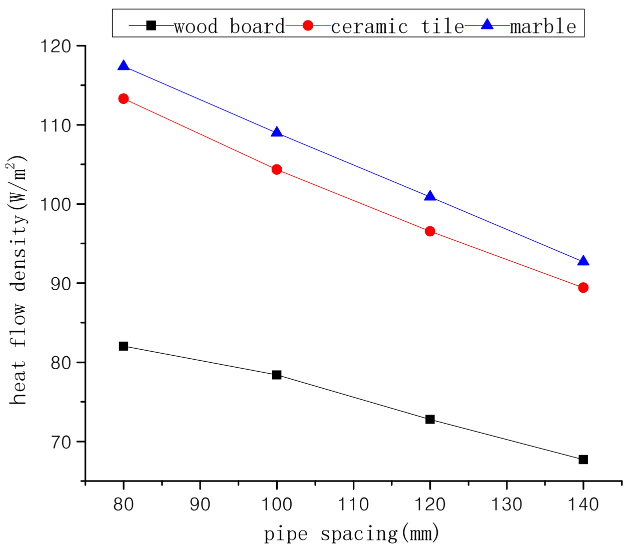


Fig.4 The Heat Flow Density of 5 mm Pipe Diameter

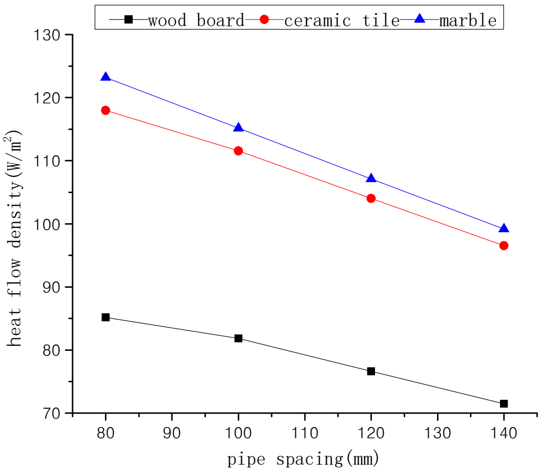


Fig.5 The Heat Flow Density of 7 mm Pipe Diameter

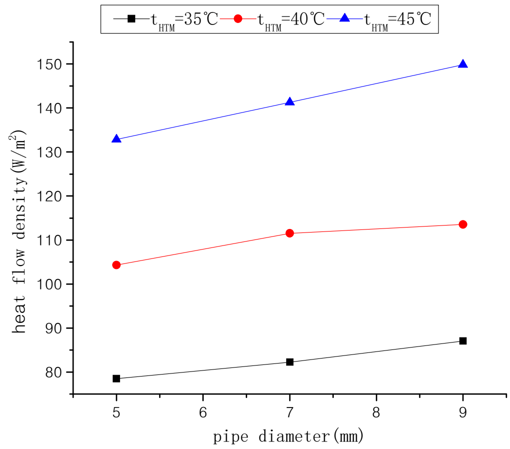


Fig.8 the Heat Flow Density of 100mm Pipe Spacing

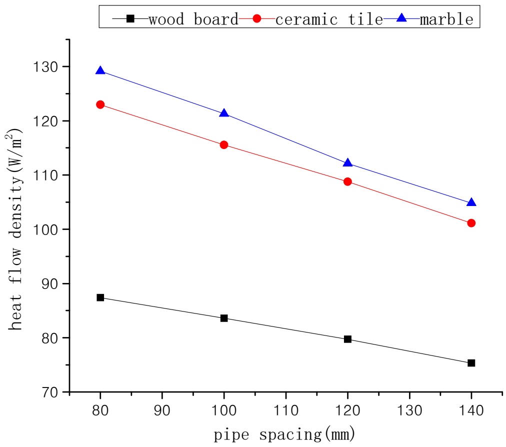


Fig.6 the Heat Flow Density of 9 mm Pipe Diameter

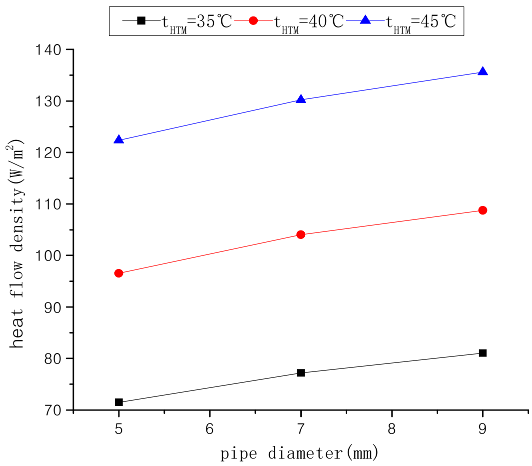


Fig.9 the Heat Flow Density of 120mm Pipe Spacing

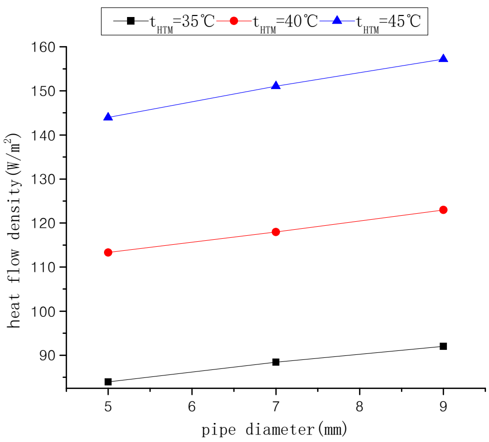


Fig.7 the Heat Flow Density of 80 mm Pipe Spacing

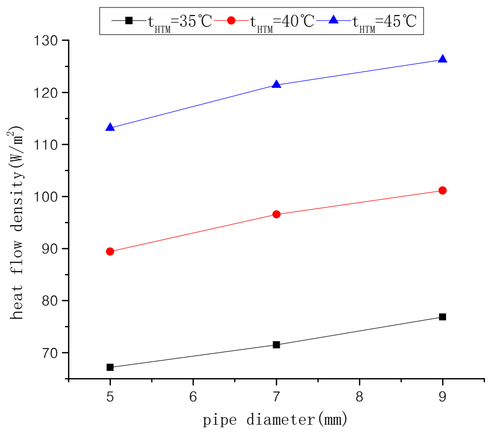


Fig.10 the Heat Flow Density of 140mm Pipe Spacing

Fig.4 to 6 present the floor surface materials' great influence on the heat flow density. The thermal conductivity of the wood is about 0.14 W/(m K) and the thermal conductivity of the marble is about 2.91 W/(m K), under the same heat medium temperature condition, pipe spacing , pipe diameter , and the marble surface heat flow density is about 2 to 3times of wood, and the smaller thermal conductivity of materials are affected easier by the pipe diameter. The heat flow density varies inversely to the pipe spacing and they have an approximate linear relationship. Considering the requirement of increasingly demanding energy, it is better to choose smaller thermal conductivity materials as far as possible. But the heavy smaller thermal conductivity materials can make the floor surface temperature to be exorbitant high so that it affects the indoor comfort. As far as three kinds of materials concerned, ceramic tile is the best choice.

By Fig.7 to 10, at the same pipe spacing and floor surface materials, the heat flow density gets higher with the pipe diameter increasing .As to the thermal release, it is advantageous to increase pipe diameter, but the increase of the diameter can make the packing layer thicker, so that it affects the economy of construction.

IV. CONCLUSION

In this paper, a comprehensive quantitative analysis and Study on the thermal characteristics of the floor radiant heat transfer process in the air source heat pump system is carried out. This paper mainly analyzes the relationship of floor heat flux and influence factors which include pipe diameter, pipe pitch, HTM temperature, indoor temperature, and topping materials. Consequently, based on the result of analyzing numerical simulation, a reliable quantitative basis for the practical engineering has been approved to apply in such aspects as design, construction and operating maintenance. Moreover, a solid foundation has been laid for its popularization and application in the future.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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