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The Low-Temperature Radiant Floor Heating System Design and Experimental Study on its Thermal Comfort

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Abstract: In order to analyze the temperature distribution of the low-temperature radiant floor heating system that uses the condensing wall-hung boiler as the heat source, the heating system is designed according to a typical house facing south in Shanghai. The experiments are carried out to study the effects of the supply water temperature on the thermal comfort of the system. Eventually, the supply water temperature that makes people in the room feel more comfortable is obtained. The result shows that in the condition of that the outside temperature is 8~15℃ and the relative humidity is 30~70%RH, the temperature distribution in the room is from high to low when the height is from bottom to top. The floor surface temperature is highest, but its uniformity is very poor. When the heating system reaches the steady state, the air temperature of the room is uniform. When the supply water temperature is 63℃The room is relatively comfortable at the above experimental condition.
Key words: low-temperature radiant floor heating system; condensing wall–hung boiler; temperature distribution; comfort

I. Introduction

Low-temperature radiant floor heating uses the low temperature water as the heat medium, and its heat coils are buried in the floor of building. It's a heating mode that uses the mechanical circulating hot water to heat the room[1]. It is comfortable, healthy, energy-saving, clean and easy to be decorated. Gradually it has attracted people's attention, and it's recognized as the ideal heating way at home and abroad. With the continuous development of floor heating technology, the relevant research is also developing. Many scholars at home and abroad have got a series of achievements in the theoretical and experimental aspects. S.Sattari and B.Farhanieh analyzed the effect of design parameters of floor heating on thermal performance, and they concluded that the floor layer material and the thickness have biggest effect on thermal performance[2]. South Korea's Gook-Sup Song had do some research that the influence of change of the floor thickness and supply water temperature on the surface temperature through the experiment measurement[3].Zhou Xinghong had done the numerical simulation about low-temperature floor radiant heating and concluded some laws about heating. These could provide theoretical basis for design, construction and operation of heating system[4]. Zhao Leilei analyzed heat transfer performance of low-temperature radiant floor heating comprehensively[5]. In Yanshan University, Dong Wei and Wu Lei, had done the research and about new control strategy and temperature controller of low-temperature radiant floor heating respectively[6,7]. Xiao Yongquan simplified the average surface temperature, non-radiative average surface temperature. He established a single-valued function whose total costs is the supply and return water temperature difference and determined the optimum supply and return water temperature difference eventually[8]. These studies had an important significance for the further development of radiant floor heating. This article mainly introduces the design and other problem of radiant floor heating system. The system uses the condensing boiler as the heating resource and the experimental heating room is faced the south in Shanghai. Through the experimental methods, the surface and air temperature distribution have been analyzed in the condition of different supply water temperature in a typical heating season. Also the supply water temperature that makes people more comfortable is obtained.

II. 1 The design of the low-temperature radiant floor heating system

The design of the low-temperature radiant floor heating system is calculating the thermal load of the experimental room which is based on the building envelope characteristics. It includes heat consumption of the exterior-protected structure, cold air infiltration heat loss and cold air invasion. According to the calculation results, it has been calculated that the thermodynamic calculations of the low-temperature radiant floor heating system. The calculations mainly include heating load, the heat per unit floor area, tube spacing, and average temperature of the earth's surface and so on.

1.1 The heat load analysis of the laboratory

The total construction area of the room is about 39.78m2 and its area could be used is 33.6 m2. The interior includes office chairs, lockers and other facilities, and the plane diagram of the house is shown in Fig.1.

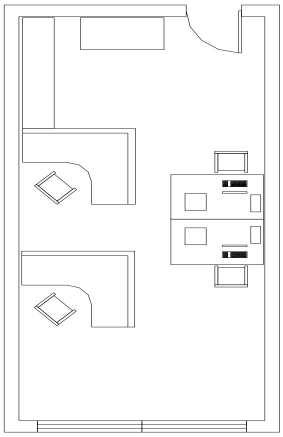

Fig.1. The Laboratory plan

The design heat load is the basis for the design of the heating system. The design heat load includes three parts, the main part is the basic heat consumption of the building structure and the other two parts are infiltration heat loss and the cold wind invasion heat loss. Because the room doesn't have the outside door, so there is no need to consider the cold invasion of consumption. The total heat consumption of the experimental room is $Q = 3159.20W$.

1.2 The surface temperature and the heat dissipation of the floor

When floor heat dissipation of the room is calculated, the impact of the indoor office desks and chairs should be taken into consideration. Q is modified, and the modified coefficient is 1.25[9]. So the result is $Q = 3949.00W$. Combined with figure1, the preliminary design is that the laying area of the heating pipe is 33.6m2, and the pipe is 300mm away from the wall. So the unit area of the required heat dissipation is $q_x = 117.53w$.

The relationship between surface average temperature t and the unit heat of the floor q_x is as follows,

$$t = t_n + 9.82(\frac{q_x}{100})^{0.969} \qquad (1)$$

q_x will be substituted into the equation (1), and average temperature of the earth's surface t=31.48℃, which matches the provisions[9].

1.3 Determination of distance between heating pipes

According to design selection table in radiant heating and cooling technical specification in China[9], the nominal diameter of the heating pipe in the system is 20mm. Its filling layer thickness is 50mm, and the polystyrene foam insulation layer thickness is 20mm, and its thermal conductivity is $0.041w/(m{\cdot}k)$. The ground layer material is stone, and its thermal resistance is $R = 0.02m^2 \cdot K / W$. The water temperature difference is designed as 10℃. Combined with q_x and t, A=200mm is chosen as the heating pipe spacing.

III. Experimental studies on temperature distribution of floor radiant heating

2.1 Experimental system of floor radiant heating

In the experimental system, condensing gas boiler is heat source and low-temperature radiant floor heating is the heating end. By heating the internal circulating water of condensing boiler, the radiant floor heating makes the experimental room warm. The pipes are arranged for double circuit type. The temperature measurement points in the room are shown in Fig.2.

Through the experimental measurement, temperature distribution are obtained in different supply water temperatures when the outdoor temperature and humidity are within the range of 8~15℃ and 30~70%RH respectively.

And then the supply water temperature that makes the room more comfortable is got.

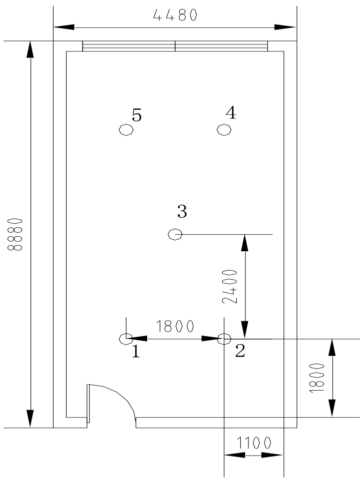

Fig.2.Support distribution

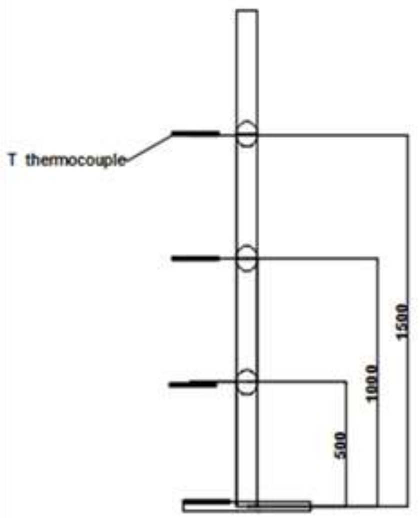

Fig.3. Temperature points distribution

In the experimental room, there are 5 measuring supports, and there are 4 measuring points in every bracket. The height of measuring points are 0m, 0.5m, 1.0m, 1.5m, and the total amount is 20. Their distribution is shown in Fig.3. The measuring points in the height of 0m are used to measure the earth's surface temperature, and the other measuring points are measuring the air temperature in the experimental room.

2.2 Experimental results and analysis

When the supply water temperature is 50℃, in the case of No.3 support, temperature variation in the unsteady and steady state are shown in Fig.3, 4.

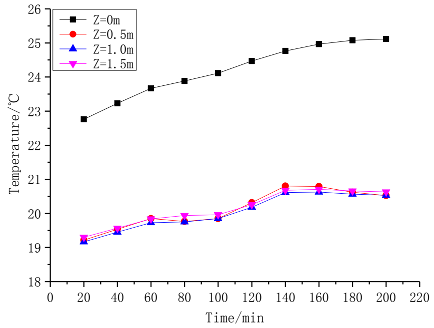

Fig.3. Temperature distribution at the beginning

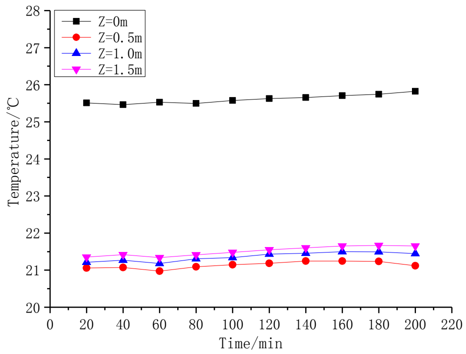

Fig.4. Temperature distribution in steady state

From Fig.3, it can be seen that the surface temperature is on the rise gradually at the beginning of the system operation, while the air temperature is on the gradual rise. During the experimental period, the surface temperature is about 3℃ higher than the air temperature. According to Fig.4, when the heating system reaches steady state, the surface temperature keeps about 25.5℃, and the indoor temperature in the height of 0.5m, 1.0m and 1.5m are about 21℃. It shows that the height has little effect on the change of temperature. The air temperature distribution is more uniform, and the temperature has no obvious change in the vertical distribution. So it can be judged that the air temperature difference between the other supports is very small. In the same height, the air temperature distribution of all supports in the experimental room is shown in Fig.5.

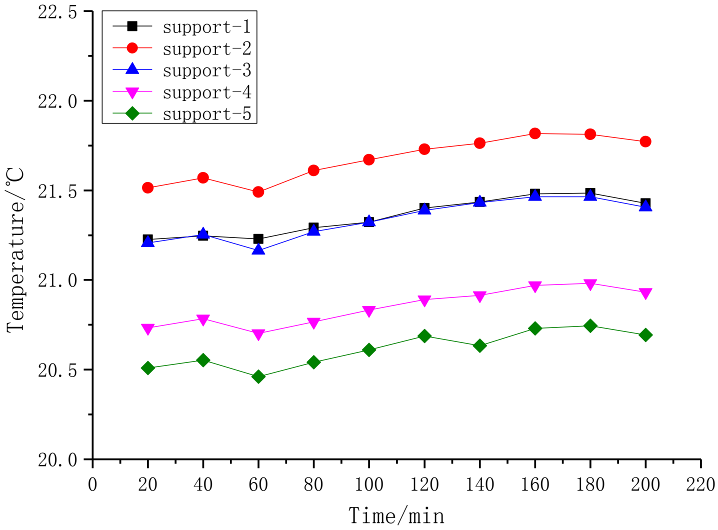

Fig.5. The temperature in different supports

It can be seen that the whole indoor air temperature is maintained at about 21℃from Fig.5. It has about 0.5℃ temperature fluctuation, and the air temperature is uniform in horizontal distribution. It can be concluded that in the condition of that the supply water temperature is 50℃, when the heating system reached the steady state, the indoor temperature reaches 21℃.

In the same way, the distribution of the surface temperature of the supports is shown in Fig.6 and Fig.7, when the heating system is in the unsteady and steady state.

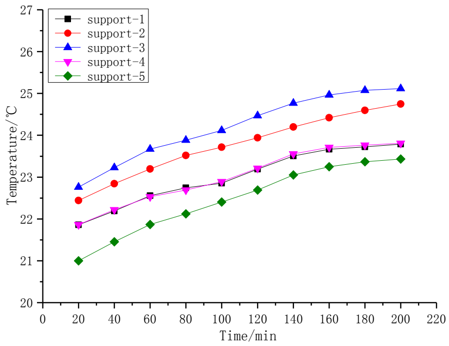

Fig.6. Ground temperature at the beginning

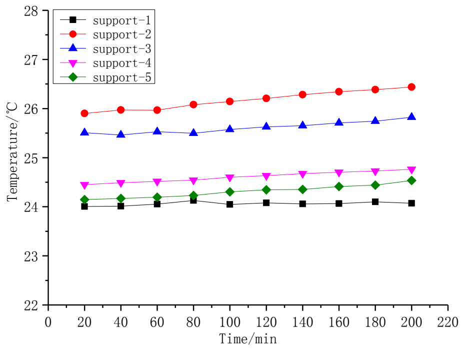

Fig.7.Ground temperature in steady state

At the beginning operation of heating system, the surface temperature distribution of 5 supports is shown in Fig.6. The surface temperature increases with the growth of time gradually. Their rise trends of the surface temperature are almost the same, but there is a certain difference in temperature between the various measuring supports. The maximum temperature difference is closed to 2℃.

The distribution of surface temperature system is shown in Fig.7 when the system reaches steady state. It is obvious that the surface temperature of every support is different, and the maximum temperature difference is about 3.5℃, which shows that the uniformity of the surface temperature distribution is poor. This is related to the position of the measuring point. When the temperature measuring points are located above the pipe, the heat transfer is better and the temperature is higher. While the other points are located at the top of the two heating tube, the temperature is lower than the former.

When the supply water of condensing boiler is 55℃，60℃，63℃，67℃，71℃，75℃ respectively, indoor temperature can be obtained and their distribution are shown in Fig.8.

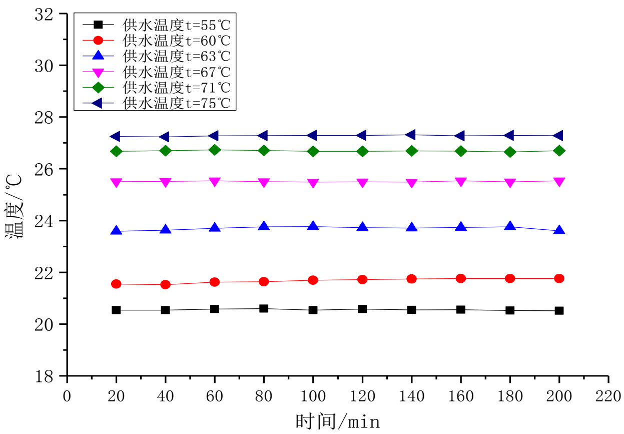

Fig.8. Temperature distribution of the room in different temperature of supply water

With the increase of supply water temperature, the indoor air temperature increase. When supply water temperature increase from 60℃ to 63℃, and from 63℃ to 67℃, indoor temperature has a large rise. The water supply temperature rise 3~4℃, and air temperature will increase about 2℃. Combined with the human factors and PMV relational table [10], it shows that when the indoor air temperature reached to 24℃, the human will feel more comfortable. Based on Fig.8, the indoor air temperature is close to 24℃ when the supply water temperature is 63℃.

IV. Conclusion

According to the condensing boiler and floor radiant heating system test, conclusions can be got as follows:
(1) The indoor temperature distribution of the floor radiant heating is generally from high to low when the

height is from lower to upper. The floor surface temperature is the highest, but the uniformity is poor. The indoor air temperature has little change, and the distribution is relatively uniform.

(2) In the condition of that outdoor temperature is 8~15℃ and outdoor humidity is from 30 to 70 %, when the supply water temperature of condensing boiler is 63℃, the heating system could bring better comfort to people.

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