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Design and Experiments of a Solar Low-temperature Hot Water Floor Radiant Heating System[1]

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Abstract: The solar low-temperature hot water floor radiant heating system combines solar energy heating with floor radiant heating. This kind of environmental heating way not only saves fossil resources and reduces pollution, but also makes people feel more comfortable. First, the authors devised an experimental scheme and set up the laboratory. Second, we collected a great deal of data on the system in different situations. Finally, we conclude that such heating system is feasible and one of the best heating methods.

Key words: solar energy; collectors; floor radiant heating

1. INTRODUCTION

"Solar low-temperature hot water floor radiant heating system" is designed to heat the space with solar hot water passing through the in-floor piping loop. The overall floor acts as the radiator for the system, of which the radiation heat transfer presents 60% (i.e. majority) of its total heat transfer. However, the ordinary heater works in reliance of air convection and always fails to generate desirable heat in the sense of comfort and health. Therefore, "solar low-temperature hot water floor radiant heating system" increasingly concerns the public[2].

2. THE GENERAL SITUATION OF PROJECT

1) The laboratory is a single floor building with two heating rooms next door lies in Beijing. Architectural area of the laboratory is 32m^2. There is a single glass reinforced plastic window with area 2.2m^2, a single glass reinforced plastic window with area 1m^{2}and a wooden door with area 3.4m^2 in the west wall. There is two single glass reinforced plastic window with area 1.6m^2 in the east wall. Thickness and height of each wall is 0.37m and 3m.

2) The index of design heating load of building is 50 W/m^2[6].The design heating load is 1360 W while the average hot-water supply heating load is 605W.The indoor design temperature is 16 ℃ while the outdoor design temperature is -9℃. The calculating outdoor temperature for heating is -1.6℃[7].

3) We select heat pipe evacuated tube collector produce by Sunpo Company. Gross area of collectors connected in series is 6m^2.We choose 3.5kW electric heater as system's auxiliary thermal source. The capacity volume of thermal storage tank installed indoor is 200L.

4) We lay cross linked polyethylene pipe as heating coil by double-spiral type in floor radiant heating system. We design the internal diameter of pipe is 16mm and the interval between every two pipe is 100mm.The design temperature of supply water is 45℃ while the design temperature of return water is 35℃.

5) We install a heat meter to measure running data of the system and to arrange 31 electric thermo-couple test points to measure distribution of indoor temperature (Fig. 1). We install two electric meters to measure electricity consumption of auxiliary electric heater and circulating water pump respectively. The starting of the auxiliary electric

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heater and circulating water pump is carried out by the automatic control system.

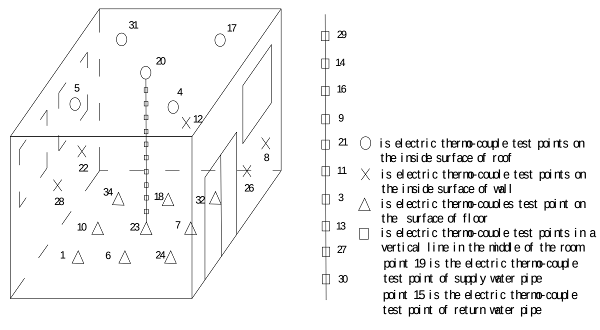

Fig.1 Distribution of electric thermo-couple test points

6) Overall capital investment of this "solar low-temperature hot water floor radiant heating system" is about 20000 RMB.

3. DESIGN STUDY

3.1. The Design of Low-temperature Radiant Floor System

3.1.1. Heating Load Calculation

[1]In the project, we usually use method of area heating index to calculate heating load according to following:

$$Q_f=\varphi Q_n=\varphi\,(q\times F\times 10^{-3}) \qquad (1)$$

Where Q_f is design heat consumption of radiant heating (W);

φ is correction coefficient, φ=0.8- 0.9;

Q_n is design heating load of the building(W);

F is architectural area of the building(m^2);

q is area heating index of the building (W/m^2).

[7]The hourly average hot water supply heating load is calculated as follows:

$$Q_{rp}=cm\rho v\,(T_r-T_l)/T \qquad (2)$$

Where Q_{rp} is the hourly average hot water supply heating load (W);

m is unit quantity of using hot water;

v is daily hot water consumption per unit(L/d);

T_r is temperature of hot water (℃);

T_l is calculating temperature of cold water (℃);

T is the number of hours of hot water supplying each day(h/d);

ρ is density of water(kg/m^3);

c is thermal capacity of water(kj/kg·℃).

Total heating load of the building:

$$Q_z = Q_n + Q_{rp} \qquad (3)$$

By calculating, the total heating load of the building is 2000W[5].

3.1.2. Structure and Arrangement of the Radiant Heating Floor

We lay cross linked polyethylene pipe as heating coil by double-spiral type in floor radiant heating system. First of all, we lay heat insulating material (polystyrene and aluminum foil, total thickness is 40mm, $\rho \geq 20$kg/m^3) under heating coil for heat insulation in only one direction. We design that the internal diameter of pipe is 16mm and the interval between every two pipe is 100 mm[4]. Because double-spiral type takes the centre of the floor as a symmetric point and then lay water supply pipe and water return pipe symmetrically, so temperature of floor in each direction is same and the length of each circuit is same. It is easy to balance resistance of circuit and to make flow quantity of circuit evenly. We divided the radiant heating floor into 4 circuits (Fig. 2).

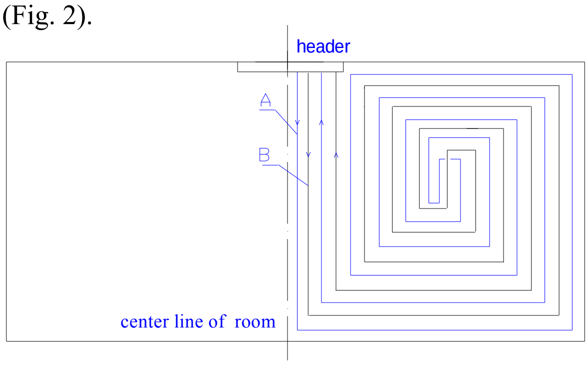

Fig.2 The arrangement of radiant heating floor

Circuit A: In one side of the room and interval is 200 mm; Circuit B: In the middle of circuit A and interval is 100 mm. Circuit C: Its circuit is the same as circuit A but in another side of room; Circuit D: Its circuit is the same as circuit B but in the middle of Circuit C. To circuit A and C, we must keep 100 mm interval between the most outside pipe and wall of room. We can turn on/off each circuit through the valve on water collecting header. Fill up layer of floor is made of crushed stone and concrete and its thickness is 30mm (Fig. 3).There has a expansion seam every 5m.The thickness of leveling layer and constructive layer is 20mm and 70mm respectively.

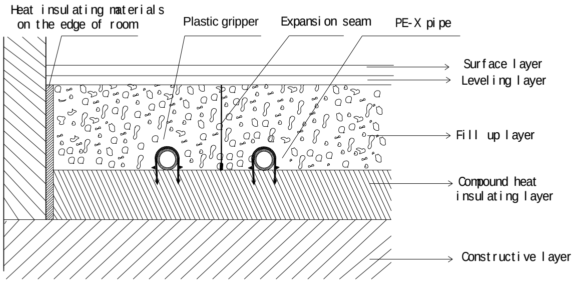

Fig.3 The structure of radiant heating floor

3.2. Design of Heat Collecting System

[1]Gross solar collector area calculation:

$$Q_u = I(\tau a) - Q_l \qquad (4)$$

Where Q_u is the heat consumption of unit square meter of the collector (W/ m^2) ;

$I(\tau a)$ is the solar radiation quantity of unit square meter of the collector (W/ m^2) ;

Q_l is the total energy loss of water tank, collector and pipeline (W/ m^2) .

By calculation, we can get that the gross solar collector area is 6 m^2. We select heat pipe evacuated tube collector (type HP8*) which is designed by Beijing solar energy research institute and produced by Sunpo company. There are three suits connected in series in the system. It is installed toward south with a inclination of 40°.

4. EXPERIMENTAL RESULT ANALYSIS

The “solar low-temperature hot water floor radiant heating system” started to run after the laboratory has been constructed. We collected the data of the system when it runs in sunny, cloudy, overcast and other various days or when it stays in continuous running, and analyzed the same as follows:

4.1. Variations in Solar Radiant Intensity

The solar radiant intensity curve(Fig. 4- Fig. 6), which is drawn and labeled according to the data collected in overcast, cloudy and sunny days, shows that during heating seasons in Beijing the solar radiant intensity appears somewhat low every morning and, within the time span from 9:00 am to 10:00 am, only keeps around 200W/m^2 in overcast days and 600W/m^2 in sunny days; almost at 12:00 am, it reaches the daily maximum i.e. 1000W/m^2 in sunny days and of 500—600W/m^2 in overcast days; it keeps going down afterwards and arrives at the daily minimum around 100W/m^2 at 4:00 pm in overcast days and 5:00-5:30 pm in sunny or cloudy days.

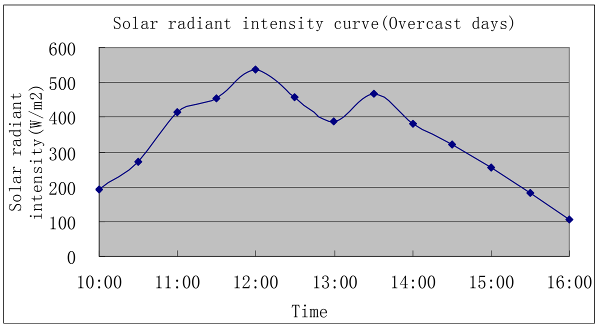

Fig.4 Solar radiant intensity curve(Overcast days)

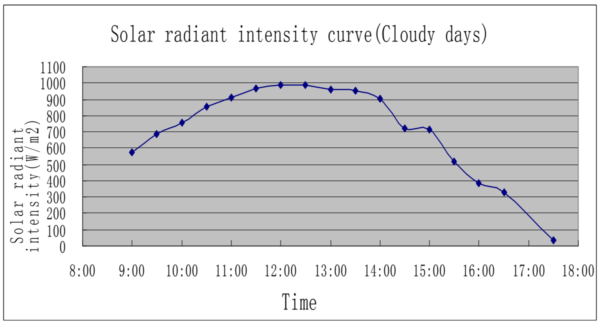

Fig.5 Solar radiant intensity curve(Cloudy days)

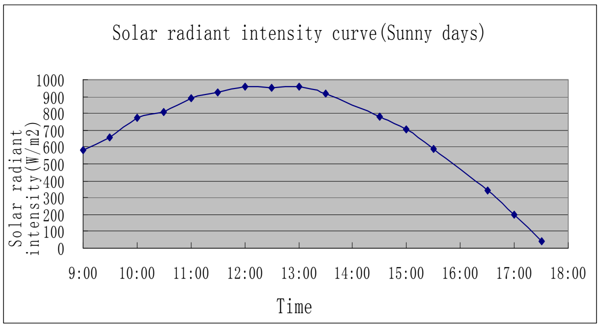

Fig.6 Solar radiant intensity curve(Sunny days)

4.2. Variations in Instantaneous Heat Collecting Capacity

The collector’s instantaneous heat collecting capacity curve(Fig. 7- Fig. 9), which is drawn and labeled according to the data collected in overcast, cloudy and sunny days, shows that during heating seasons in Beijing the instantaneous heat collecting capacity appears almost zero in overcast and cloudy days but 0.6kW in sunny days around 9:00 am; within time span from 12:00 am-2:00 pm, it reaches the daily maximum around 2kW in cloudy days but not in sunny days, because the efficiency to transfer light into heat keeps low when the solar radiant intensity keeps low, which means the instantaneous heat collecting capacity turns out to be low, and it increases when the solar radiant intensity increases, which means the instantaneous heat collecting capacity turns out to go up, however, the temperature of the water in the collector will meanwhile increase which will instead cause lower instantaneous heat collecting capacity, therefore, the maximum instantaneous heat collecting capacity in cloudy days is higher than that in both sunny and overcast days; it turns back to zero within 5:00-6:00 pm.

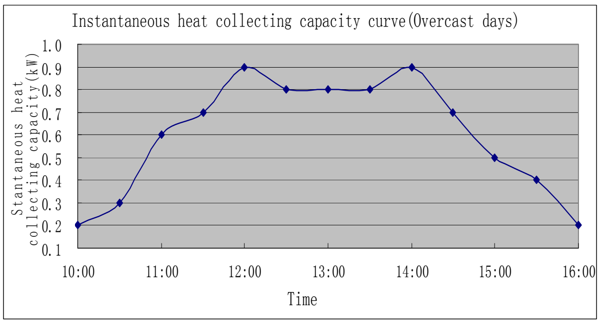

Fig.7 Instantaneous heat collecting capacity curve(Overcast days)

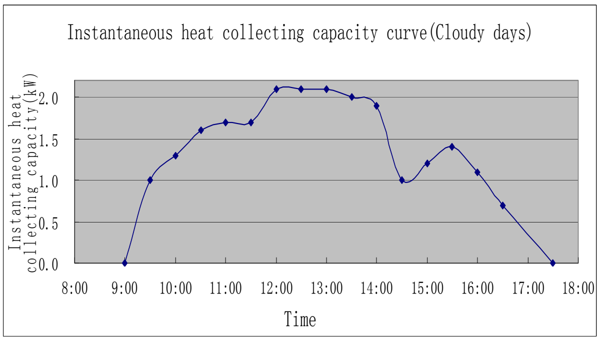

Fig.8 Instantaneous heat collecting capacity curve(Cloudy days)

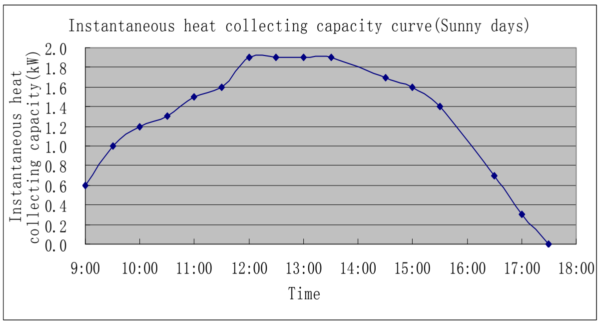

Fig.9 Instantaneous heat collecting capacity curve(Sunny days)

4.3. Variations in Temperature of Heat Collecting System

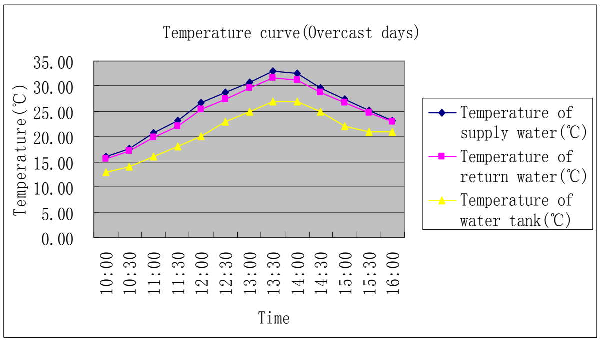

Fig.10 Temperature curve(Overcast days)

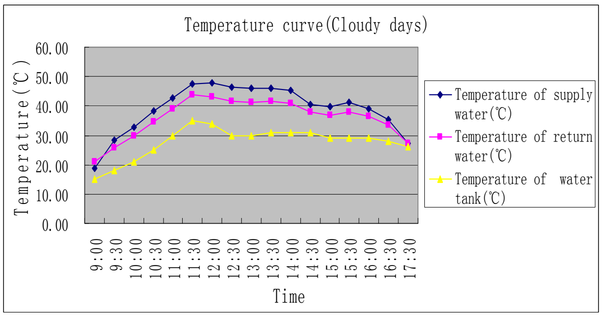

Fig.11 Temperature curve(Cloudy days)

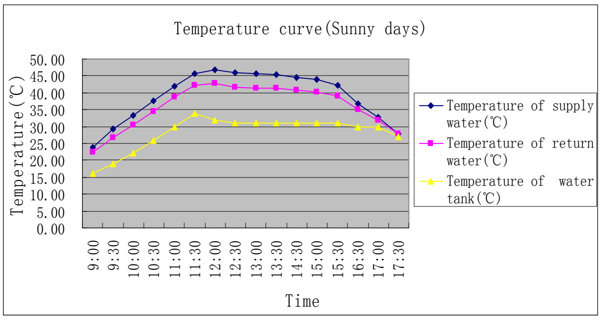

Fig.12 Temperature curve(Sunny days)

The temperature curve of heat collecting system(Fig. 10- Fig. 12), which is drawn and labeled according to the data collected in overcast, cloudy and sunny days, shows that around 9:00 am, the heat collecting system's fluid inlet and outlet temperature of the collector and the water tank temperature both stays around 10□ or more in overcast and cloudy days and, however, the water tank temperature still keeps around 10□ or more but the heat collecting system's inflow and outflow temperature can reach 20□ or more in sunny days; the heat collecting system's fluid inlet and outlet temperature of the collector and the water tank temperature increases when the solar radiant intensity increases, and it reaches the daily maximum within the span from 11:00-12:00 am in cloudy and sunny days but within the span from 1:00-2:00 pm in overcast days; it keeps going down afterwards when the solar radiant intensity keeps going down; if the fluid inlet temperature of the collector becomes low enough to dissatisfy relevant requirements, the automatic control system will power off the circulating water pump of the heat collecting system and turn on the electric heating system, when the temperature of water tank is high enough to meet relevant requirements, it will restart the circulating water pump of the heating system.

4.4. Variations in Collector Efficiency

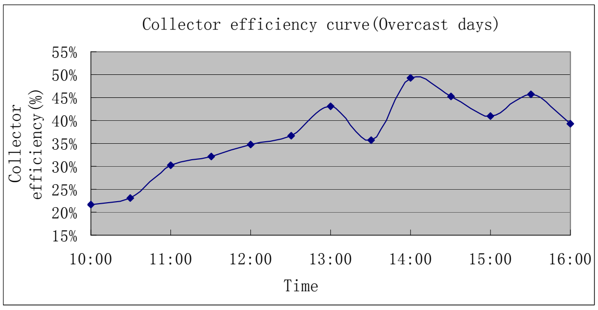

Fig.13 Collector efficiency curve(Overcast days)

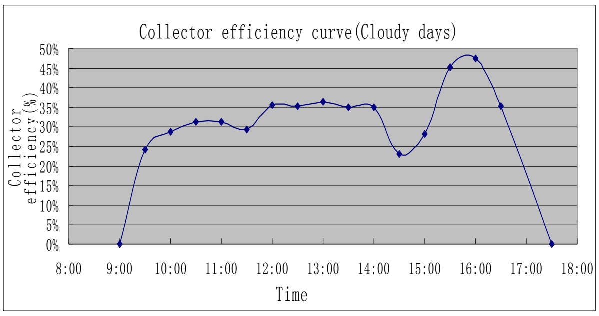

Fig.14 Collector efficiency curve(Cloudy days)

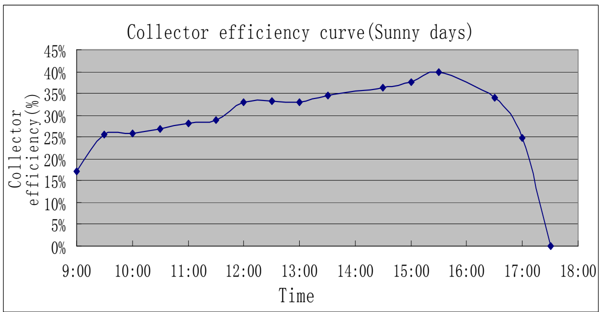

Fig.15 Collector efficiency curve(Sunny days)

The collector's heat collecting efficiency means how much calorie a collector can transfer the light into[3]. The collector's heat collecting efficiency curve(Fig. 13- Fig. 15), which is drawn and labeled according to the data collected in overcast, cloudy and sunny days, shows that around 9:00 am, the heat collecting efficiency appears almost zero in cloudy and overcast days, but can reach 10%-20% in sunny days; it will increase when the solar radiant intensity increases, and the temperature of the water in the collector will increase as well; however, when the temperature of the water in the collector becomes high enough, the heat collecting efficiency will go down instead; therefore, the heat collecting efficiency has a fluctuate tendency to increase in the day time, and will arrive at the daily maximum generally around 2:00 pm in overcast days and around 4:00 pm in cloudy and sunny days; and it will gradually go down to zero afterwards.

4.5. Status in Continuous Running

We recorded the data of the system when it kept staying in continuous running during the period from 10:00 am on January 22, 2005 to 10:00 pm on January 23, 2005. It started to run at 10:00 am on January 22 and the solar collector served as the heat source for the floor radiant heating system. The heating load necessary for heating were fully borne by the solar collector from the starting to 5:00 pm. During such heating period, all equipments and instruments reasonably consumed electricity 3-4 kWh. The solar collector absorbed enough solar energy in the day time not only to heat the space and water necessary for day-time life, and also to allow excessive heat to be saved in the heat storage tank. When the heat collecting system stopped running, the heat saved in the heat storage tank was generally enough for another 3-5 hour heating. When the temperature of the water tank was low enough to dissatisfy the heating demand afterwards, the automatic control system will turn on the electric heater for heating, which averagely consumed electricity 1-2 kWh.

4.6. Technical Feasibility Analysis

We can find out from the experiment that, at most time during the period from November to December, the heat collected by the heat collecting system in day time is enough to satisfy the day-time heating demand of the heating system for. Moreover, the heat saved in the heat storage tank in the day time is enough to satisfy the night-time heating demand. Namely, the electric heater is not necessary in November and December during the heating seasons.

In January during the heating seasons, the collector's heat collecting efficiency can reach 30%-40% in most of the day time and even arrive around 50% if conditions available, which almost can satisfy the demand for day-time heating. Furthermore, the heat saved in the heat storage tank in the day time was generally enough for another 3-5 hour heating in cloudy and sunny days. At night or in overcast days, if the heat collected by the heat collecting system is not enough to satisfy the heating demand, we can use the electric heater to enable the heating system to desirably heat the indoor space.

The above analyses tell us that the designed "solar low-temperature hot water floor radiant heating system" is feasible.

5. CONCLUSIONS

We may conclude from the design and research of this system, as well as the operation and analysis of the experiment, that the floor radiant heating system is the best design to heat in conjunction with solar energy. The "solar low-temperature hot water floor radiant heating system" can satisfy desirable heating demand and provide a comfortable space. It is somewhat purported to protect the environment and remarkably save energy. It can be widely used and operated in northern regions where heating is required. The increase of people's living standard will cause the "solar low-temperature hot water floor radiant heating system" to be used in increasingly-wide area.

REFERENCES

[1]. Deying Li. Heat- supply Engineering. Beijing: China Architectural Industry Press.2004. (In Chinese)

[2]. Yanling Na, Guangbei Tu.A New Heating Way——Solar Energy Floor Radiant Heating System. Proceedings of National HV&AC and Refrigeration in 2002.Beijing: China Architectural Industry Press.2002. (In Chinese)

[3]. Williams, J.R (American) write, Yuwen ZHAO translate. Design and Installation of Solar Heating and Hot Water System. Beijing: New Times Press. 1990. (In Chinese)

[4].Technical Specification Applied for Low -temperature Hot Water Floor Radiant Heating(DBJ/T 01-49-2000).(In Chinese)

[5]. Code for Design of Building Water Supply and Drainage(GB 50015-2003). (In Chinese)

[6]. Lindong ZHAO. Probe into the Square Thermal Index of the Heat- supply System. Exploitation of Scientific Information and Economy.2004, 14(6): 128-129. (In Chinese)

[7].Yaoqing LU. Practical Handbook for Design of heat-supply and Air-conditioning. Beijing: China Architectural Industry Press.1993. (In Chinese)