Conference Proceedings

EuroSun 2014

Aix-les-Bains (France), 16 - 19 September 2014

One Solar Heating and Hot Water Supplying Combined System for Rural Area Buildings

Li Aisong[1], Li Zhong[2], Liu Zongjing[2], Jia Chunxia[2], Feng Airong[2]

[1,2]Institute of Building Environment and Energy Efficiency, China Academy of Building Research, Beijing (China)

Abstract

Based on the actual situation of Chinese rural area buildings, we designed one kind of solar heating and hot water supplying combined system, which integrated all-glass vacuum tubes solar air collector and soil heat storage system. The system comprised solar air collecting system, hot air transmission system, soil heat storage system and domestic hot water system. The solar air collecting system provided hot air through hot air transmission system, the hot air transmission system could change hot air flow direction-in heating season, connected to soil heat storage system, supplied heating for room; in non-heating season, connected to domestic hot water air-water heat exchanger, supplied hot water while enhanced indoor and outdoor air convection, so that reduced the indoor temperature. The system features were: 1. Solving overheating in non-heating season and freeze in winter of the traditional solar hot water systems; 2. Usage of soil heat storage reducing investment and construction costs; 3. Heat dissipation was mainly through radiation, so the thermal comfort was greatly improved compared with all-air heating; and 4. It could realize full year effective usage of the solar energy.

Keywords :Rural area buildings; solar air collector; soil heat storage; solar heating; domestic hot water

1. Introduction

At present, China rural area winter heating still mainly rely on firing coal or firewood, which is not only difficult to guarantee indoor thermal environment, but the fuel combustion efficiency is also lower. Active solar water heating systems are limited by several factors such as system and installation costs, antifreeze, anti-overheating requirements, therefore whose usage are not yet mature currently. Solar air heating currently often use pebble-bed, which increase construction costs and material costs. And the use of the phase change materials have a relatively higher costs (Lin Kunping, et al., 2005). The flat-plate solar air collectors have larger heat loss, whose collecting efficiency is not higher compared with all-glass vacuum tube solar air collectors, the outlet temperature is lower, so it is not conducive to storing heat and making hot water with hot air (Zhu Dunzhi, et al., 2011).

In recent years, active solar heating system gradually become a hot topic, several single building solar heating system pilot projects have been established, such as Beijing Sunpu office building, Beijing Pinggu new rural construction projects, Lhasa railway station and so on, but the solar district heating heating pilot project is not yet mature. However, the technology itself is not the main obstacle to the promotion of solar collector heating, but the higher initial investment as well as the overheating problem in spring, summer, autumn and other non-heating season. It requires the use of seasonal energy storage with ground source heat pumps or other forms complementary to achieve but for currently weak economic foundation of rural areas, which is not applicable (Zheng Ruicheng.2013).

In response to these problems, we develop the system.

doi:10.18086/eurosun.2014.03.01 Available at http://proceedings.ises.org

2. System introduction and performance analysis

2.1. System introduction

The project site is located in Dunhuang City, Gansu Province, China. The building is single layer village residential house, whose heating area is 79.5 ㎡, and facing west. The demand of domestic hot water is 120 l/d at 55℃. The demand of space heating is 64.18 kWh/m^2·a under the room temperature of 16℃ (date:10.27~3.15). The building roof is flat, and on the middle living room, there is set color steel sloping roof, whose slope is equal to the local latitude, where the all-glass vacuum tube collectors are installed. The system schematic are shown in Fig.1 and Fig.2:

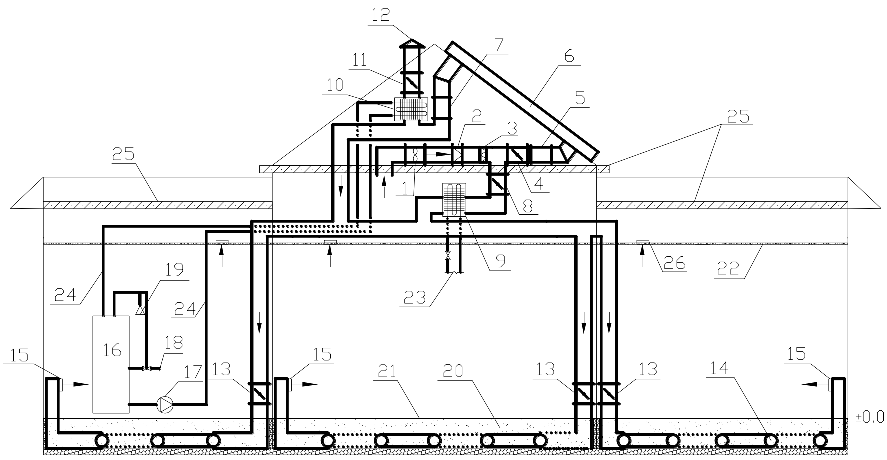

Fig. 1:The system schematic

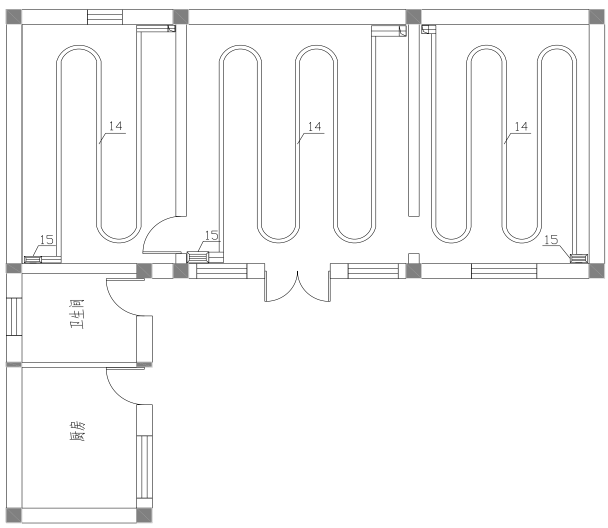

Fig. 2 The metal heat exchanger coil installation schematic

Note: Figures in Fig. 1 and Fig. 2 indicate the following meaning:

1, fan; 2, check valve; 3, filter; 4, electric valve; 5, air distribution header; 6, solar air collectors; 7, air collection box; 8, electric valve; 9, air-water heat exchanger for auxiliary heat; 10, air-water heat exchanger for domestic hot water; 11, electric valve; 12, wind cap; 13, manual adjustment air valve; 14, metal heat exchanger coil; 15, air outlet; 16, hot water storage tank; 17, the primary circulating pump for domestic hot water; 18, cold water connection; 19, hot water unit; 20, soil heat storage bed; 21, floor; 22, ceiling; 23, hot water pipe for auxiliary heat source system; 24, the primary side pipe for domestic hot water system; 25, flat roof.

Working principles of the system are:

1. supplying heating and heat storage with solar air collectors:

In heating season, under abundant sunshine condition, electric valve 4, manual adjustment air valve 13 and fan would be opened, electric valve 8, 11 would be closed, the indoor air would flow through solar air collectors, then the hot air would flow through metal heat exchange coil of soil heat storage system, partial heat would be stored in soil bed, the warm air would be sent into room. The air collectors would be used for room space heating and soil heat storage.

2. Supplying heating with soil heat storage system

In heating season, in the case of there is sufficient heat storage in soil, the fan would be closed at night, heat the room by radiant from soil storage bed.

3. Supplying heating with auxiliary heat source system

In heating season, when there is not enough solar energy or not sufficient heat storage in soil, auxiliary heat source, fan and electric valve 8 would be opened, electric valve 4 would be closed. The indoor air would be heated by air-water heat exchanger of auxiliary heat source. The auxiliary heat source may be boiler or central heating water.

4. Domestic hot water supplying in non-heating

In non-heating season, under abundant sunshine condition, electric valve 4, 11and fan would be opened, electric valve 8, manual adjustment air valve 13 would be closed, the indoor air would flow through solar air collectors, then the hot air would flow through air-water heat exchanger of domestic hot water system. Meanwhile, the primary circulating pump for domestic hot water would be opened, then the water in tank would be heated for domestic hot water supplying. The operation would not only enhance indoor and outdoor air convection, but also solve the problem of collecting system overheating.

The actual installation of the system are shown in Fig.3 and Fig.4:

Fig. 3:The solar air collectors

Fig. 4:The metal heat exchanger coil

2.2. Introduction of all-glass vacuum tubes solar air collector

In this system, we used high collecting efficiency vacuum tubes air collectors. Compared with solar water collector, the solar air collect has advantages of: 1. no freeze problem in winter; 2.few leakage of air would less impact to collector performance. 3. no corrosion problem, so it is convenient for winter heating, enhancing indoor ventilation, solar drying and other occasions (Yuan Yingli,et al.2010).

Considering both in non-heating seasons preparation of hot water and in heating season soil heat storage require higher air temperature, the system used vacuum tube collectors with higher air collector efficiency. The size of the collector is 2290 mm (length) ×1820 mm (width) ×225 mm (thickness), the inlet and outlet diameter both is 75 mm. For single block, the gross area is 3.25 m^2, the aperture area is 2.05 m^2. The collector structure is shown in Figure 5. The basic working principle of the collector is: the tube inner layer absorbing solar radiation, converting into heat, when using a fan to force the cold air blowing into the collector, then the air entering the metal intubation, forced convection formed in the annular region, thereby heating the air to obtain a higher temperature.

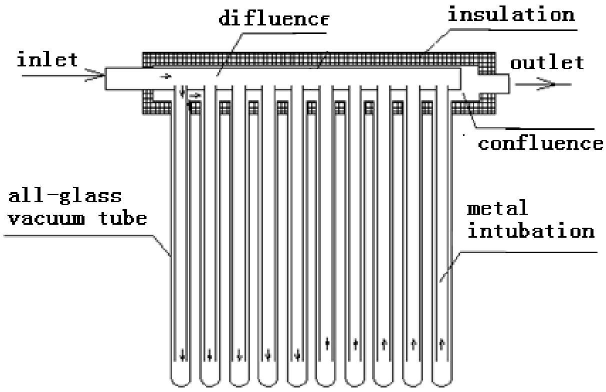

Fig. 5: The collector structure diagrammatic drawing

By testing, in the condition of average total irradiation of 785 W/㎡, average outdoor temperature of 10.7℃, when the flow rate is 81.4 m³/h and the inlet temperature is 17.0℃, the average outlet temperature is 79.2℃. The average collector instantaneous efficiency based on the total area is 40.5% (shown in Fig. 6), The collector instantaneous efficiency curve equation based on the aperture area is:

$$\eta_a = 0.7124 - 6.1959 T_i^* \quad \text{(eq. 1)}$$

$$T_i^* = (t_i - t_a) / G \quad \text{(eq. 2)}$$

Where η_a is the instantaneous efficiency; T_i^* is the normalized temperature difference, (㎡·℃)/W; t_i is the inlet temperature of the air, ℃ ; t_a is the outdoor temperature, ℃ ; G is the total irradiance on collector aperture area, W/㎡ .

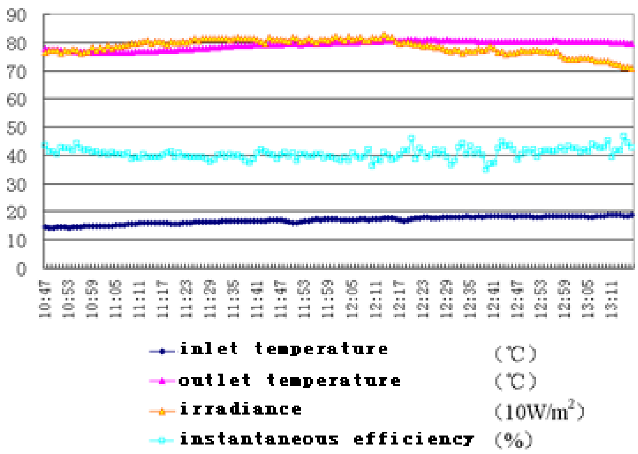

Fig. 6: The collector thermal performance test data

We also tested the collector's air flow resistance. As shown in Fig.7, when the air flow rate is 90 m³/h, the resistance of the collector is lower than 200 Pa. Therefore, when the flow rate is lower than 100 m³/h, the pressure loss is relatively small, the fan power is small, so the fan selection restrictions is also small.

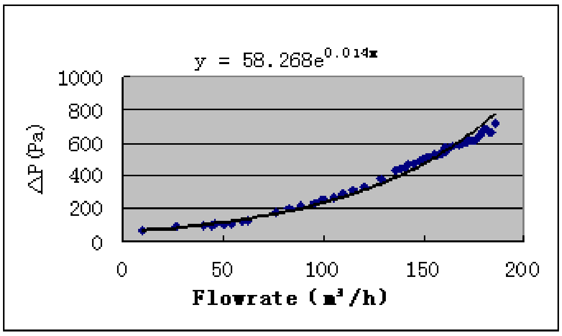

Fig. 7: The collector resistance performance test data

3 System performance analysis

3.1. Simulation analysis

The meteorological datas of Dunhuang are:

1. The annual average daily solar irradiation on horizontal plane: 17.48 MJ/(m^2·d);
2. The annual average daily solar irradiation on local latitude angle plane: 19.92 MJ/(m^2·d);
3. The December average daily solar irradiation on local latitude angle plane: 15.88 MJ/(m^2·d);
4. The average daily hours of sunshine: 9.2 h;
5. Heating season average outdoor temperature: -2.8 ℃;
6. Calculating outdoor temperature for heating: -12.6 ℃;
7. Ventilation calculating outdoor design temperature in summer:29.9 ℃.

According to the local meteorological data, we used trnsys to simulate related parameters, and optimized the system(Fig.8). In the simulation, we didn't set auxiliary heat source. From the simulation we could get that in heating season when only relid on air collectors heating, the outlet temperature of the collectors is in 40 ℃ ~90 ℃ (Fig.9), the inlet air temperature of the three rooms is in 17.5 ℃~20 ℃ (Fig.10). The three rooms temperature was simulated, we could see that when there is not auxiliary heat source and personnel heat dissipation, the lowest temperature is 8℃, which could meet the basic requirement of rural area.

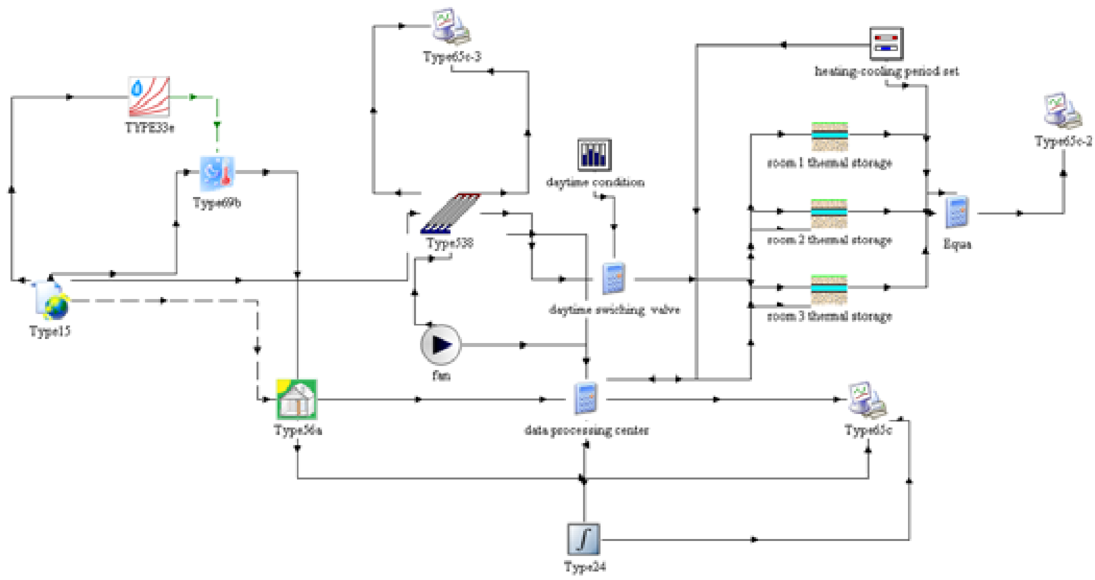

Fig. 8: The simulation program

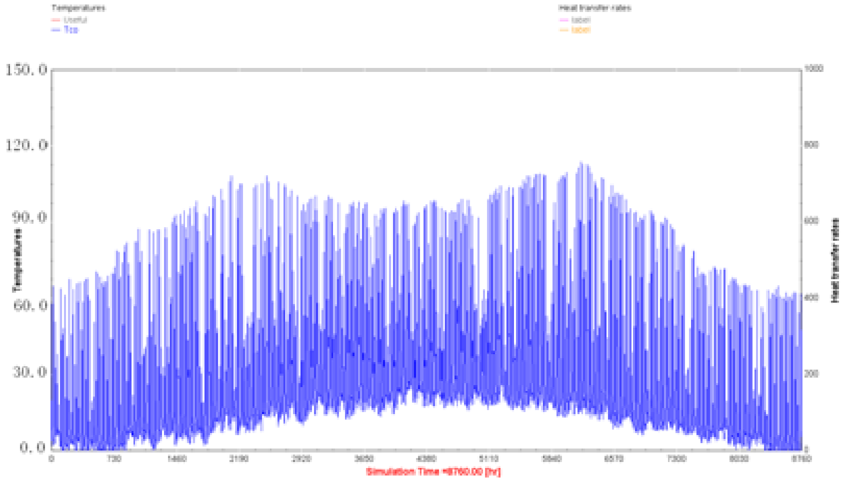

Fig. 9: The collector annual outlet temperature

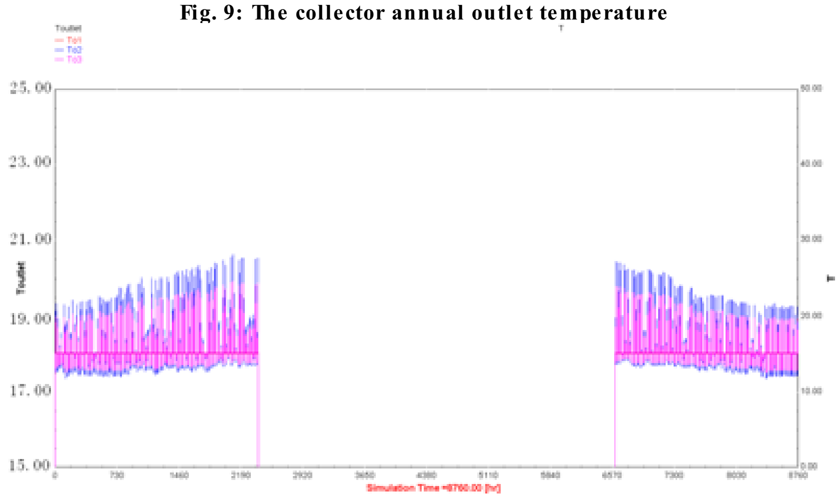

Fig. 10: The inlet air temperature of the three rooms

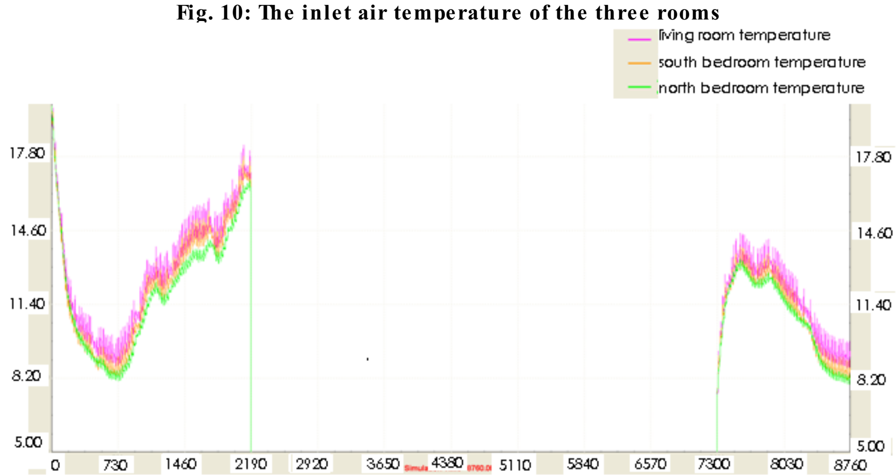

Fig. 11: The air temperature of the three rooms

3.2. Actual operation analysis

At present, the project and the monitoring system have been completed. In the user stay, the monitoring system will run throughout the year to conduct real-time monitoring, data monitoring platform provides GPRS remote function, the monitoring data are readily available in the office.

Now we have get the data of domestic hot water supplying in non-heating seasons (Tab.1 and Tab.2).

Tab. 1: Non-heating season domestic hot water supplying test data

Test Date	Average outdoor temperature (℃)	Irradiation on aperture area (MJ/m²)	Average outlet temperature of the collecting system (℃)	Average temperature of the tank after operation (℃)
5.27	21.5	22.6	105.8	57.6
5.28	23.1	23.6	109.2	60.3
6.11	19.5	14.5	80.3	49.2
6.13	21.0	22.7	105.6	57.5

Tab. 2: Non-heating season domestic hot water supplying compute data

Test Date	Heat gain of the collecting system (MJ)	Heat gain of the domestic hot water system (MJ)	Collecting system efficiency
5.27	74.97	30.15	0.40
5.28	79.82	31.26	0.41
6.11	50.25	24.56	0.43
6.13	75.25	30.67	0.40

From the test data we can see that domestic hot water provided by the system can fully meet the demand. The collecting system could provide very high temperature hot air. And the system has a high energy saving effect in non-heating seasons. As current is in the non-heating season, room heating conditions cannot be tested, following heating season of this year we will get the further test data.

4. Conclusion

The system integrates all-glass vacuum tubes solar air collector and soil heat storage system, it has the following advantages:

1. The system uses air as heat medium, avoiding antifreezing problem and rehydration problem caused by fluid leakage for collecting system which uses water as heat medium.

2. The system adopts compacted soil as heat storage medium prime form, avoiding the problems of large construction, high costs and pebbles damp moldy for using pebble bed heat storage. At night, by using radiant heating, improves thermal comfort.

3. In non-heating season, the system can be used to prepare domestic hot water by high-temperature air, which not only solves the problem of overheating in summer for general solar collecting systems, but also enhanced the indoor air flow, reduces the indoor temperature. This measure also increases the utilization of renewable energy throughout the year.

4. To further reduce system costs, the system adopts manual control, which is characterized by cheap, reliable, easy to use and easy to operate.

5. The system has the advantages of simple structure, low costs, easy to control, high security and high solar energy utilization. It is suitable for widely using in rural area housing, and it has high promotional value.

5. Acknowledgements

We are grateful to the 12th Five-year Plan Period National Key Technology R&D Program: Task of Village and Town Buildings solar energy Use Key Technology Research and Demonstration (2011BAJ08B08).

6. References

Lin Kunping,et al.2005. Experimental study of underfloor electric heating system with latent thermal storage an air supply.Acta Energiae Solaris Sinica 2005 (06), 820-824.

Yuan Yingli,et al.2010. Analysis of thermal performance of evacuated tubular solar air collector with inserted tubes. Acta Energiae Solaris Sinica 2010 (06), 703-708.

Zheng Ruicheng.2013. Chinese solar heating technology status and development. Construction Science and Technology 2013 (1), 70-72.

Zhu Dunzhi,et al.2011.Application of air collector solar heating system in building. China Renewable Energy Society 2011 Annual Conference,Beijing.