

Study on performances of heating system with solar hybrid air source heat pump in winter

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Abstract. Taking Tianjin as an example, a time schedule for household hot water supply was set up. By simulating hot water supply and space heating in 24 hours, running performances of the system, hybrid by solar and air source heat pump, were studied under the unfavorable heat supply conditions in the month with minimum solar radiation. The interaction between the performances of hot water supply and space heating was analyzed.

1. Introduction

Heating system of solar hybrid air source heat pump was widely used in household hot water supply and space heating, because of its energy saving, high efficiency, safety, environmental protection and large amount supply of hot water. In the cold areas of China, the temperature in winter is lower, the climate is dryer and the solar irradiance is reduced, but the heating amount needed by the users is greater; meanwhile the more higher of the outdoor relative humidity was, the more restrictions there were for the solar hybrid air source heat pump application. In this paper, taking Tianjin as an example, the performances of hybrid system were studied under the disadvantage heating conditions in winter, and the interaction between the performances of hot water supply and space heating was analyzed.

2. Experimental System

The hybrid heating system studied in this paper was composed of air source heat pump, solar heating unit, heat storage tank, data acquisition instrument and meteorologic parameter tester. The main equipment and technical parameters were shown in Table 1 and Figure 1. In this hybrid system, solar heating loop and air source heat pump heating loop were connected to the lower part and middle part of water tank respectively. Hot water was directly supplied from the top part of water tank. Space heating loop was connected to the upper part of water tank, and simulating the user's heating demand with a plate type heat exchanger.

Table 1. Main equipment and technical parameters

Main equipment	Main technical parameters
Air source heat pump	Rated heating capacity:5.20 kW, Rated hot water capacity:110 L/h, Rate power:1.27 kW,Cryogen:R22/1.15 kg,COP:4.08;
Solar heating unit	Solar heat collector area:4m ² ,Maximum working pressure:0.6MPa;
Heat storage tank	Tank capacity:300 L, Maximum pressure of water tank:0.8 MPa;



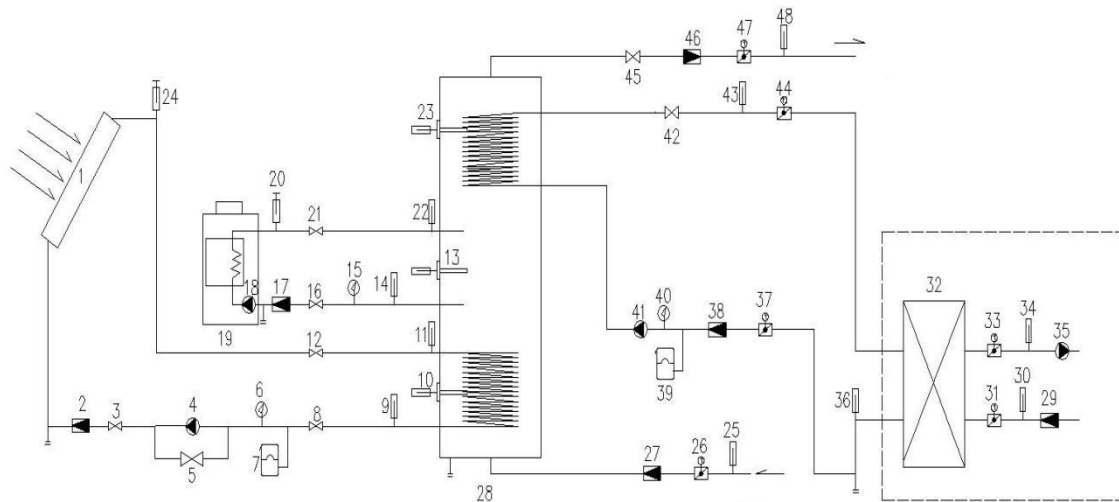


Figure 1. Test system

1-solar collector; 2,17,27,29,38,46- electromagnetic flow meter; 3,5,8,12,16,21,42,45-regulating valve; 4,18,35,41-pump; 6,15,40-pressure gauge; 7,39-expansion tank; 9,10,11,13,14,20,22,23,24,25,30,34,36,43,48- temperature sensor; 19-air source heat pump; 28-water tank; 26,31,33,37,44,47- electromagnetic valve; 32-plate-type heat exchanger.

3. Experiment Condition

The experiment was carried out in Tianjin, taking a residential house with 100 m² as an example. According to the Code for Design of Building Water Supply and Drainage[1], daily hot water consumption was set to 300L and heat load 4kw, 24 h was taken as an experiment period, and the typical space heating day in winter in Tianjin was selected to carried out performance test of hot water supply and space heating. According to the domestic and foreign relevant standards[2-6] and the residents' water using habits in Tianjin, the hot water supply schedule was set up. During the experiment, the user's hot water supply time and the heat consumption should meet the regulation of Table 2.

Table 2. Schedule for heat consumption of discharged hot water

Time	8:00	9:00	11:00	13:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00
Ratio of heat consumption to daily total heat supply /%	10	5	10	10	5	5	5	10	10	15	15

Researches showed that the traditional air source heat pump can safely and reliably running with outdoor air temperature above -3 °C[7], the daily average temperature of Tianjin in winter (November to January) is -4~5 °C[8], and the minimum monthly average daily radiation is in December. Combined with the frost map[9] of the air source heat pump in Beijing and Tianjin area, December 26th and 27th, 2017 were selected as the typical test days. From 8:00 of December 26th, 2017 to 8:00 of December 27th, 2017 (recorded as Test Day 1) and from 8:00 of December 27th, 2017 to 8:00 of December 28th, 2017 (recorded as Test Day 2), the changes of outdoor temperature and humidity were recorded in Figure 2(a) and Figure 2(b).

At the beginning of the experiment, solar heat collector loop was closed, heat pump was opened and its heating temperature was set to 55 °C, water tank was set to terminal temperature of 45 °C. The

solar heating loop was opened, when the outlet water temperature of collector was 4 °C higher than the value of tank lower part in the heating process, and closed with 2 °C higher. The space heating loop can achieve the heating load of 4 kw by adjusting the cooling water with flow rate and temperature. Experiment started from 8:00 and kept running continuously for 48 hours, water was discharged according to Table 2 by 4 L/min (5% heat consumption ratio) or 6 L/min (10% and 15% heat consumption ratio) respectively. Data acquisition instrument was used to record the temperature parameters every 15s, that is, the inlet and outlet temperature of the air source heat pump, the inlet and outlet temperature of the solar heat collector, the temperature of supply and return water for space heating cycle, the water temperature of the heat storage tank, the water temperature of the hot water supply, the temperature of the tap-water; the flow rate parameters of the heat pump system, the solar heat collector, space heating circulation and hot water supply.

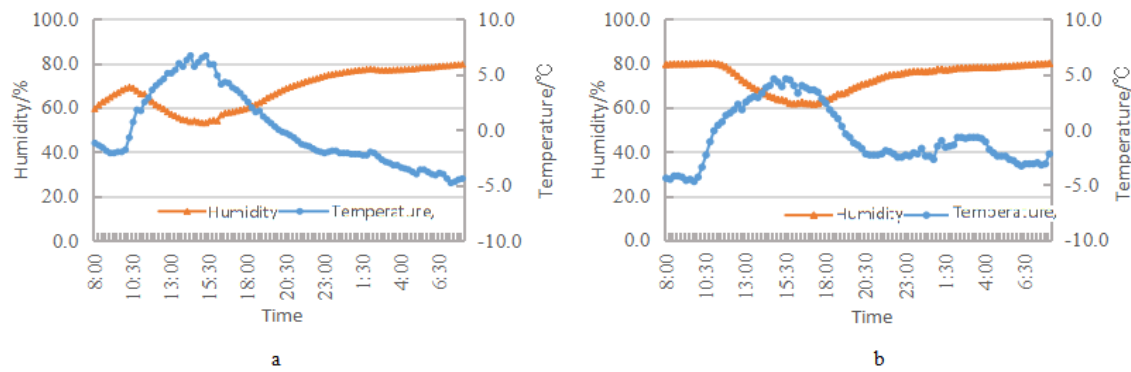


Figure 2(a). Outdoor temperature and humidity changes in Test Day 1

Figure 2(b). Outdoor temperature and humidity changes in Test Day 2

4. Results and Analysis

4.1. Parameter Calculation of Thermal Performance

(1) Heat supply by heat pump

$$Q_{hp} = \frac{\sum_{i=1}^n c \times \rho \times q_1 \times \tau_i \times (t_2 - t_1)}{60} \quad (1)$$

In it, Q_{hp} was heat supply by heat pump in test period, kj; c was specific heat capacity of water, here $c=4.18\text{kJ}/(\text{kg} \cdot ^\circ\text{C})$; ρ was density of water, here $\rho=1.00\text{kg/L}$; q_1 was circulation flow rate of heat pump, L/s; t_1 and t_2 were inlet and outlet water temperature of heat pump respectively, °C; τ_i is data collection interval, s.

(2) Heat supply by solar heater

$$Q_{sh} = \frac{\sum_{i=1}^n c_s \times \rho_s \times q_2 \times \tau_i \times (t_3 - t_4)}{60} \quad (2)$$

In it, Q_{sh} was heat supply by solar heater in test period, kj; c_s was specific heat capacity of medium in solar heater, here $c_s=3.70\text{kJ}/(\text{kg} \cdot ^\circ\text{C})$; ρ_s was density of medium in solar heater, here $\rho_s=1.07\text{kg/L}$; q_2 was circulation flow rate of solar heater, L/s; t_3 and t_4 were inlet and outlet medium temperature of solar heater respectively, °C.

(3) Heat consumption of space heating

$$Q_{cs} = \frac{\sum_{i=1}^n c \times \rho \times q_3 \times \tau_i \times (t_5 - t_6)}{60} \quad (3)$$

In it, Q_{cs} was heat consumption of space heating in test period, kj; q_3 was circulation flow rate in space heating cycle, L/s; t_5 and t_6 were supply and return water temperature of space heating cycle respectively, $^{\circ}\text{C}$.

(4) Heat consumption of hot water

$$Q_{ch} = \frac{\sum_{i=1}^n c \times \rho \times q_4 \times \tau_i \times (t_7 - t_8)}{60} \quad (4)$$

In it, Q_{ch} was heat consumption of hot water in test period, kj; q_4 was circulation flow rate in hot water supply, L/s; t_7 was water temperature, $^{\circ}\text{C}$; t_8 was cold water temperature, $^{\circ}\text{C}$.

Heat supply of heat pump and solar heating cycle in Test day 1 and Test day 2 were shown respectively in Figure 3 and Figure 4, temperature changes of supply and return water for space heating cycle and hot water supply were shown in Figure 5 and Figure 6, system heat consumption were seen in Figure 7 and Figure 8. Running performances and mutual influences between hot water supply and space heating of the hybrid system were analyzed as follows.

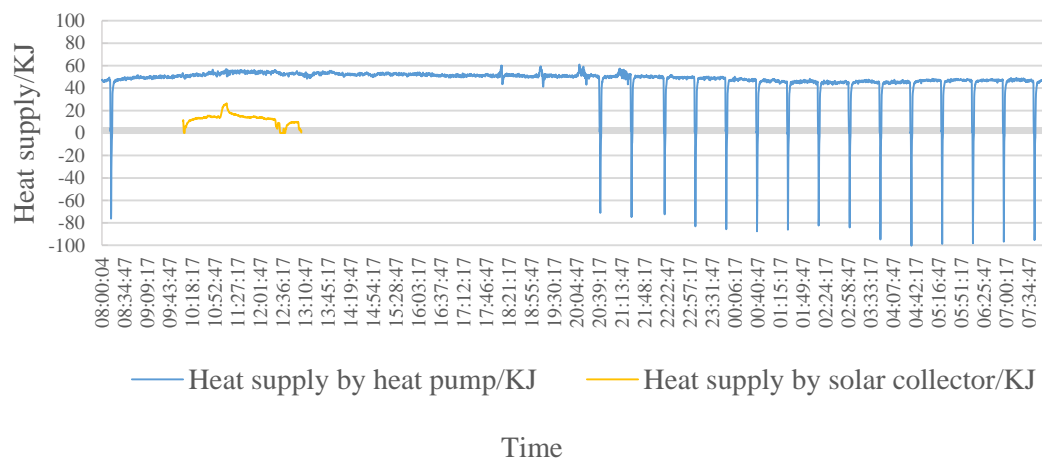


Figure 3. Heat supply in Test Day 1

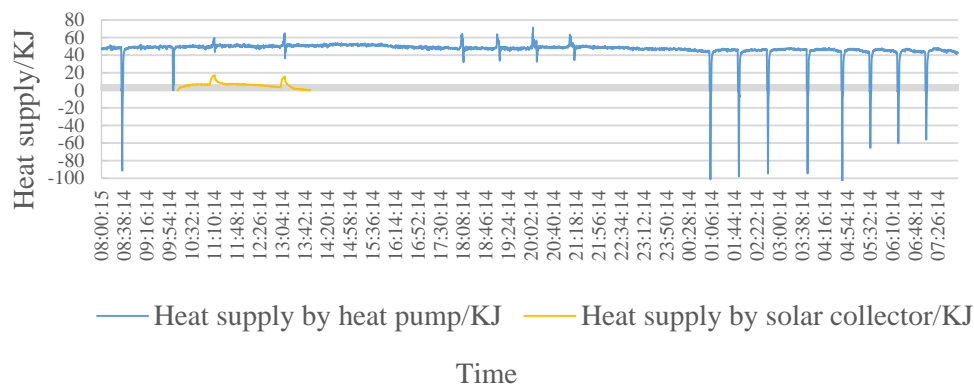


Figure 4. Heat supply in Test Day 2

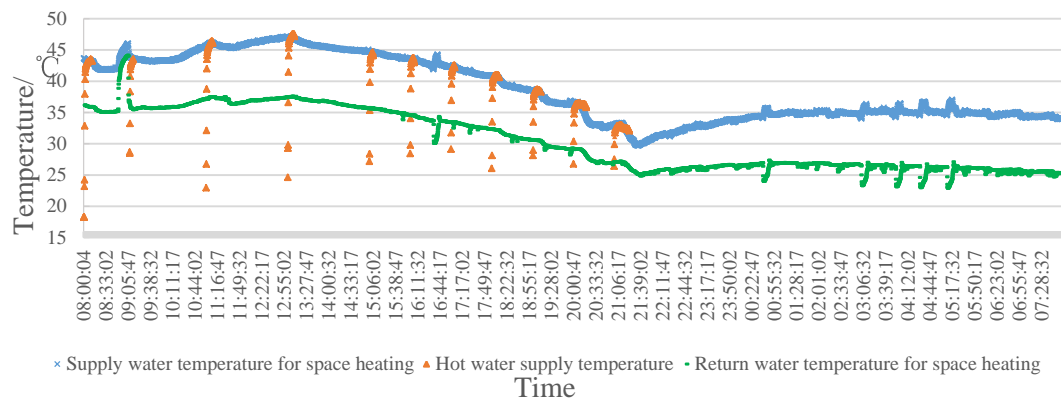


Figure 5. Water temperature changes in Test Day 1

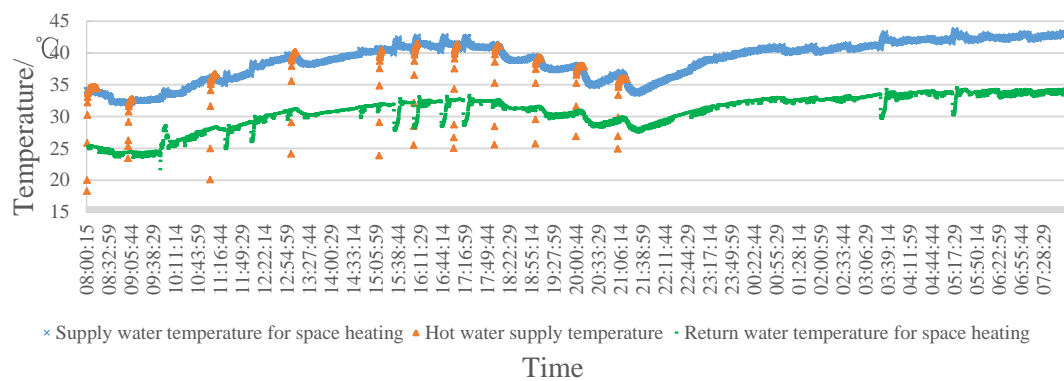


Figure 6. Water temperature changes in Test Day 2

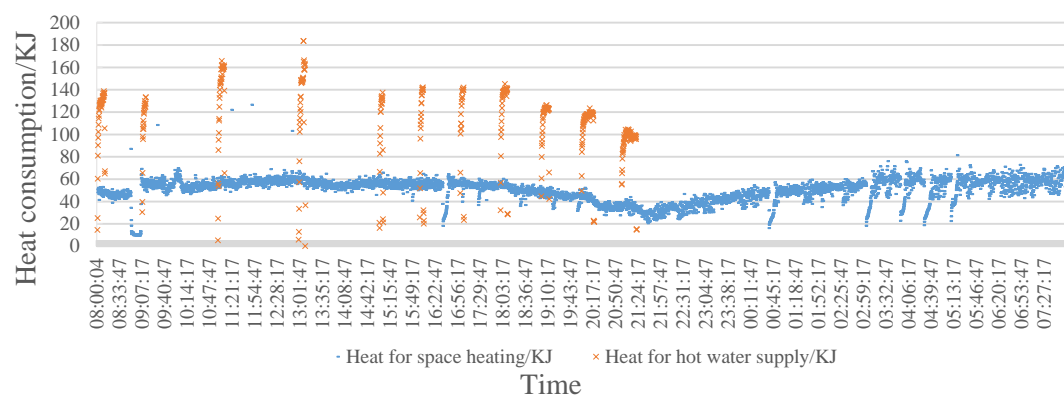


Figure 7. Heat consumption in Test Day 1

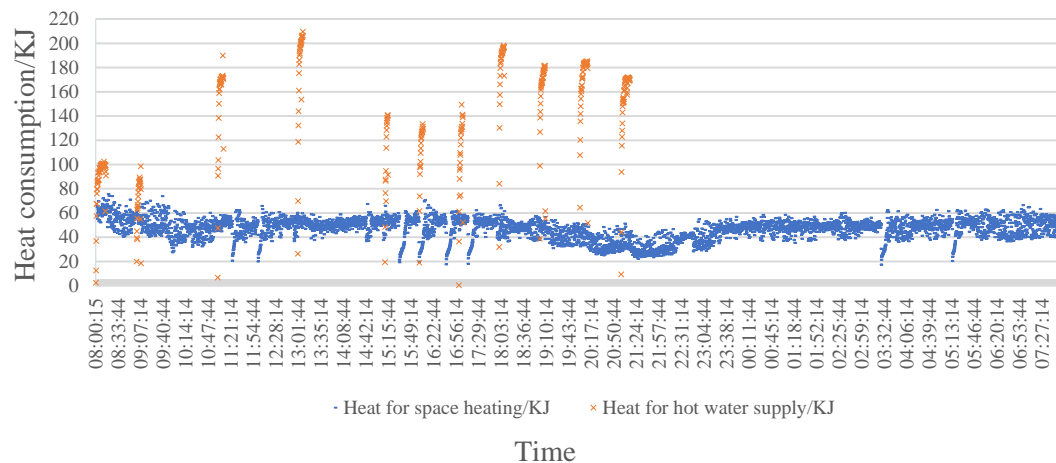


Figure 8. Heat consumption in Test Day 2

4.2. Thermal Performances of Hybrid System

Compared with Figure 3 and Figure 4, it was known that the instantaneous heat supply of heat pump and solar heat collector was respectively influenced by the discharging hot water. As the process of hot water supply, the bottom of water tank was supplemented with a large amount of low temperature tap-water, so the water temperature of solar loop inlet, connected to the lower part of the water tank, dropped sharply, and the instantaneous heat production of solar collector increased sharply. With the end of the moment discharge, water supplement was stopped, then the instantaneous heat production of the solar heat collector was gradually reduced and falling back to the value before fluctuation.

For the heating loop of heat pump, compared with the temperature of water tank upper part at the beginning of the two test days, in Test Day 1 near 45 °C and Test Day 2 near 35 °C. Under working condition of Test Day 1, the heat consumption in hot water discharge and space heating had little influence on the instantaneous heat production of heat pump, for the water discharge moment before 18:00, instantaneous heat production didn't had obvious fluctuations, and after 18:00, the large capacity discharge moment caused small fluctuations. On Test Day 2, fluctuation of heat pump instantaneous heat production had obvious fluctuation with external heat supply, that was, the large capacity discharge moment except 8:00 (the heat discharge ratio of 10% and 15%), with the end of each discharge, instantaneous heat production of heat pump fluctuated violently, first rising and then decreasing sharply, then rise to near the value before fluctuation; 8:00 and the small capacity discharge moment with discharge ratio of 5%, the external heat supply of the system did not cause obvious fluctuations in instantaneous heat production.

4.3. Hot Water Supply Performances of Hybrid System

From Figure 5 and Figure 6, it was known that the hot water discharged from the two test days of the system shown that the water temperature first went up rapidly and then tended to be stable. As the temperature measuring point was placed on the pipeline, which connected water outlet and tank, so in the initial time of water discharge, the measuring value was corresponding to the temperature of storage water in the pipe; the longer the time interval was, the greater the temperature was affected by the ambient temperature, and the corresponding temperature would only be effective when the temperature of discharging water tended to be stable; comparing the heating capacity of heat pump 110L/h (about 1.8L/min) and the hot water discharge rate of 4L/min or 6L/min, the heating rate was not enough to supplement heat consumption caused by water discharge; the temperature of discharged hot water was all above 30, as domestic hot water using terminal, hot water demand of user in winter can be basically met[10].

4.4. Space Heating Performances of Hybrid System

Design load of space heating was set at 4 kw, as shown in Figure 7 and Figure 8, the significant

fluctuations of space heating load in the two test days occurred after water discharge moment of 19:00, with large amount of water discharge at the moment of 19:00, 20:00 and 21:00, the instantaneous space heating load decreased first and then increased, then it gradually stabilized and rose near to the design value; on the Test Day 1, the lowest space heating load appeared at about 21:50, corresponding to the supply water temperature for space heating of 35 °C and the heating load of 1.6kw; on the Test Day 2, the lowest space heating load appeared at about 21:20, corresponding to the supply water temperature for space heating of 34 °C and the heating load of 1.7kw; compared with space heating load, on the two test days, from 19:00 to 1:00 of second day, the actual space heating load of hybrid system was obvious lower than the design value, and the space heating demand of users could not be met.

5. Conclusion

For running performances of heating system of solar hybrid air source heat pump in winter, hot water supply and space heating conditions was simulated in a whole day long of 24h. Combined with the daily running data of space heating in the minimum radiation month of Tianjin in winter, the operation characteristics of hot water supply and space heating were analyzed. Conclusions were as follows: (1) The instantaneous heat production of hybrid heating system was significantly affected by hot water discharge. (2) Only space heating was running, heating capacity of heat pump tended to be stable; if, meanwhile, there was large capacity discharge of hot water, that would cause heating capacity of heat pump violent fluctuation. (3) when there was hot water discharge, the actual space heating load of system was significantly affected by hot water discharge. (4) On the two test days in this experiment, between 18:00 and next 1:00, system space heating can not meet the demand of design load, to improve the heating performance in winter and improve the user's thermal experience, high heat capacity heat pump or various energy sources, such as gas boiler, could be configured.

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