Research on Operation Strategy of Solar Assisted Air Source Heat Pump System

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Abstract: Solar-assisted air source heat pump (SAASHP) has greatly improved the operating efficiency of the system. However, the operational performance of the key modules in the combined system is not clear. So a solar-assisted air source heat pump radiant heating system was established and a SAASHP was monitored. The key parameters of the solar collector outlet water inlet water temperature, and water tank temperature under different combined operation modes were calculated. The solar collector heat collection efficiency, system COP, and the energy consumption ratio under the corresponding mode were given. The solar collector heat collection efficiency, system COP, and the energy consumption ratio under the corresponding mode were given. Photo thermal conversion, evaporative heat transfer, and energy conversion between the condensers. By comparing the operating characteristics of each combination mode, the characteristics of SAASHP combined operation are finally obtained.

Keywords: Solar energy; Air source heat pump; Energy efficiency analysis; Operation strategy

1. Introduction

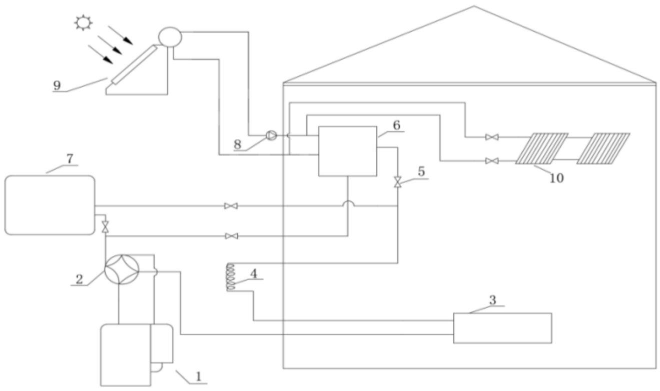
As the issue of energy and environmental protection becomes more prominent, the negative effects brought about by the use of non-renewable energy based on heating models are increasingly unable to meet the requirements of sustainable development in society [1-2]. Air source heat pumps (ASHP) have become one of the most widely used applications for a variety of heat pump types because of their low energy consumption and small environmental impact. However, when the temperature in winter is lower than the air dew point temperature and lower than 0°C, frost issues may occur on the outdoor heat exchanger coil surfaces [3-6].

To solve this problem many experts conducted research, and SAASHP greatly improved the system's operating efficiency [7-9]. Xiaolong Lv et. al.[8] studied a novel solar-assisted auto-cascade heat pump cycle model with the zeotropic mixture of R32/R290 and the results showed that it has 4.23-9.85% and 4.37-9.68 improvement compared to the ASHP. M. Shan [9] et al. researched an integrated active solar and ASHP water heating system with a passive house in cold climate. They confirmed the benefits of the ASHP system combined with solar system. However, there are few studies involving the operational performance of each module in the auxiliary operation of SAASHP. Therefore, this paper studies the SAASHP combined operation strategy, and calculates the heat collection efficiency of the collector, the system COP and the energy consumption ratio under the corresponding module, and then obtains the photothermal conversion, the evaporative heat transfer and the energy relationship between the condensers in the system. By comparing the special operations of each combination mode, the characteristics of the combined operation of the SAASHP are finally obtained.

2. Experimental system

2.1 System introduction

The system diagram is shown in Fig2-1. The experimental system is located in the air-conditioning energy-saving office on the eighth floor of an experimental building in North China. The laboratory area is 22 ㎡, and the system is consisted of the solar collectors, thermal storage tank, Capillary circulation and heat pump system. The indoor cooling ends include capillary networks and air conditioners.



1 compressor, 2 4-way transfer valve, 3 indoor air conditioner, 4 throttle valves, 5 valves , 6 fluorine water plate heat exchanger, 7 outdoor heat exchangers,8 pumps, 9 solar collectors, 10 capillary network

Figure 1-1. The solar-assisted air source heat pump diagram

2.2 System operation mode

The system can generate multiple combinations of operating modes according to its own characteristics. This system mainly discusses the auxiliary forms of SAASHP. The specific operating strategy is shown in Table 2-1 below.

Table 2-1. Realizable operation modes

Mode	Solar thermal collector	Heat exchange	Evaporator	Air conditioner	Radiation Capillary
Mode 1	Daytime run	Nocturnal run	Daytime run	Whole day run	Whole day stop
Mode 2	Daytime run	Whole day stop	Daytime run	Daytime run	Nocturnal run
Mode 3	Daytime run	Daytime run	Nocturnal run	Whole day run	Whole day stop
Mode 4	Daytime run	Whole day stop	Nocturnal run	Nocturnal run	Daytime run

3. Comparison of system operation strategy

3.1. Combined Operation Mode Comparison

The single ASHP, SAASHP and the solar capillary radiant heating system can be combined to operate in the following four joint operation modes. The following is a comparative analysis of the differences in the operation of the four modes.

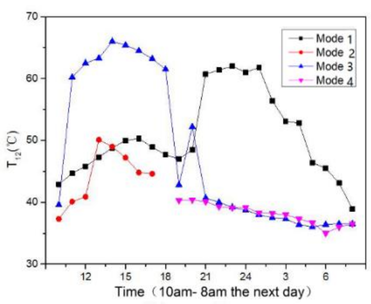


Figure 3-1. Comparison of T12 in four modes.

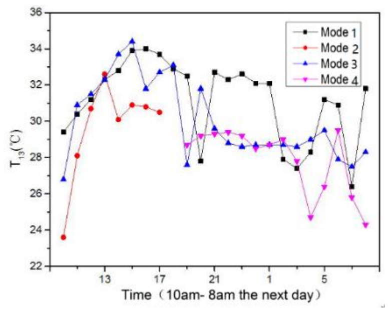
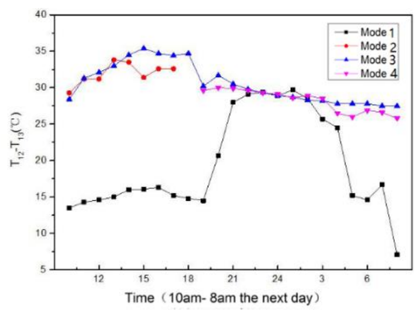


Figure 3-2. Comparison of T13 in four modes.



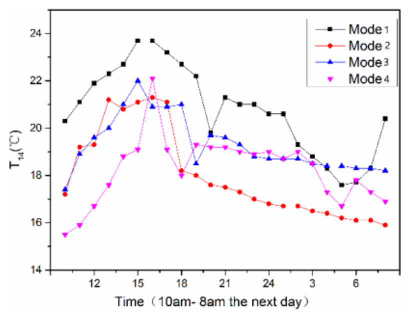


Figure 3-3. Comparison of T12 and T13 in four Modes**. Figure 3-4.** Comparison of T14 in four Modes**.**

The air conditioner refrigerant inlet and outlet temperature trend of four modes were shown as Figure.3-1, Figure.3-2 and Figure.3-3. It can be seen that the temperature in the combination of solar auxiliary mode in the daytime and night is highest, however the ASHP has a lower temperature in night compared to daytime. T12 is obviously different in different modes. In general, the air source

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heat pump is greatly affected by the day and night, thus resulting the T12 has a greater change in Mode 3 compared to Mode 1.

For the refrigerant outer temperature T13, there are little difference at daytime between ASHP and solar power assistance, however, the T13 is lower in ASHP compared to solar assisted heat pump. The temperature difference between T12 and T13 is basically maintained at about 20°C, but the temperature difference between Mode 1 is smaller.

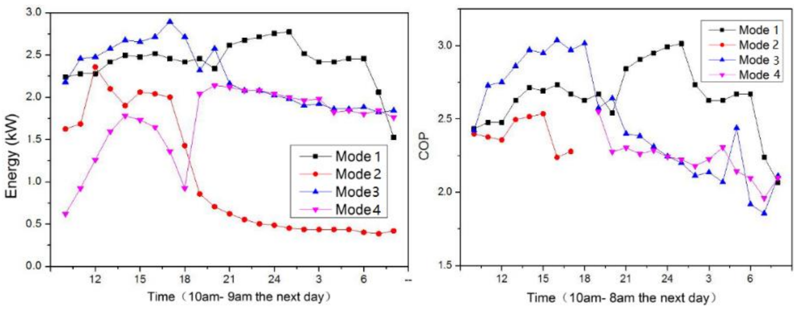
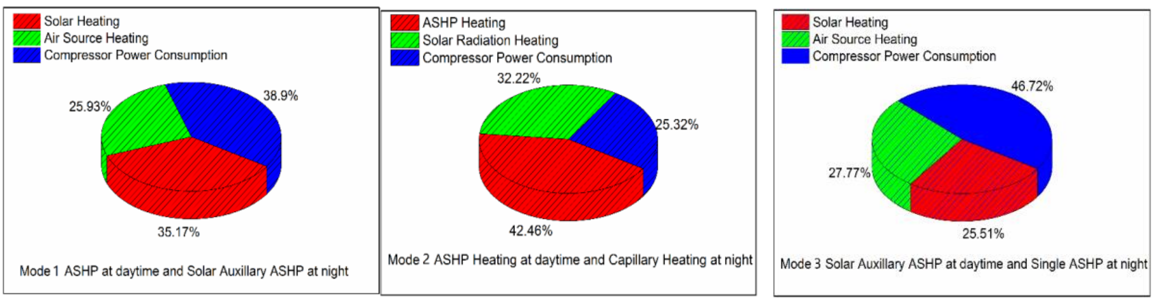


Figure 3-5. Comparison of heating power and COP in four modes.

The Figure 3-5 shows the comparison between the four modes of heating power and COP. It can be seen that the highest heating power is the solar assisted heat pump, followed by the ASHP, and finally the capillary radiant heating. In four mode, the Mode 1 has the most stable heat and the outdoor temperature during the day is relatively high. The ASHP has better heating effect. The water stored in the water tank is used to supply the auxiliary mode at night so that the heat source can be stable during the night. The trend of COP is similar to that of heating. The night-time heating COP of ASHP is much lower than that of daytime, which is more suitable for daytime use. The calculation results show that Mode 1 has the highest average COP.



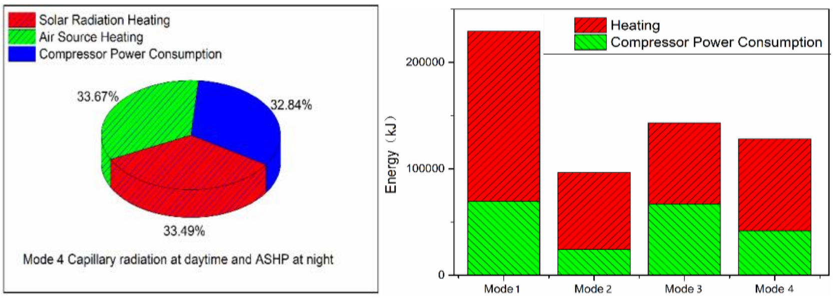


Figure3-6. Comparison of energy share heating and power consumption of compressor in four modes.

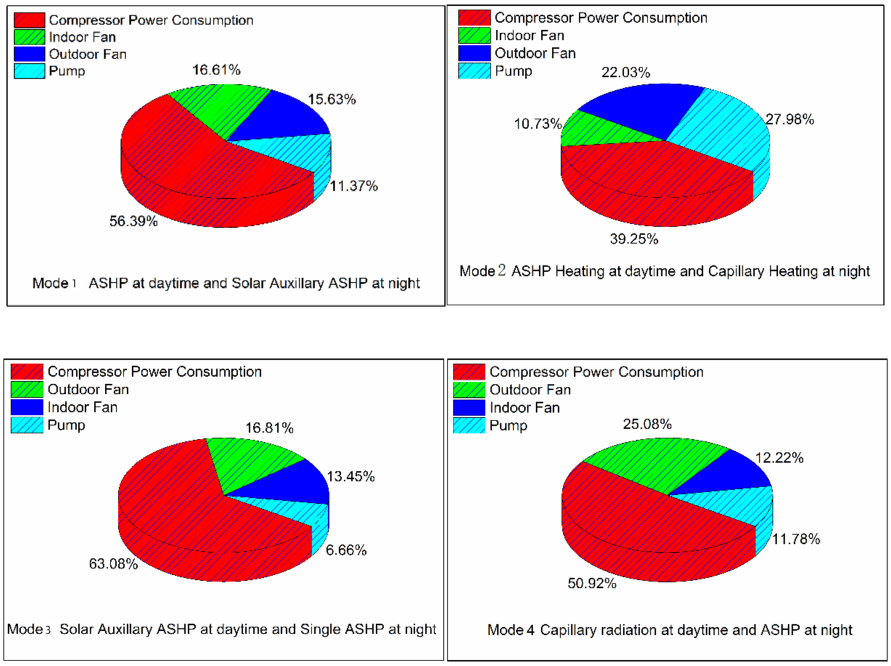


Figure 3-7. Comparison of share of power consumption in four modes.

By contrasting the energy ratio of the pie shown as Figure.3-6, Mode 2 has the smallest proportion of compressor, which is 25.32%. Mode 4 represents the largest proportion of energy consumption. This is mainly because solar radiation heating does not require the work of the compressor. Mode 2 uses capillary heating method, and capillary mode operation time is longer, energy consumption is reduced greatly. Similarly, the energy consumption of Mode 4 is lower than that. For Mode 3, solar energy auxiliary and air source heat pump require the work of the compressor to make heat, and the air source heat pump is less efficient at night causing less heat.

From the histogram in Figure3-6, it can be seen that although the proportions of energy consumption in Mode 2 and Mode 4 are smaller, but the heating capacity of one day in Mode 2 is the lowest among the four modes, while Mode 4 is the lowest. Mode 1 has the highest heat production per day, and its energy consumption is average in all four modes, and it is also a more energy-efficient mode.

From Figure3-7, it can be seen that the proportion of compressors in each mode of the compressor is the highest. The energy consumption of the compressor is high, thus resulting its proportion high. This makes the combination of the air source and solar energy assisted Mode 1 and Mode 3 consume more energy. Mode 2 capillary runs longer and it has lower overall power.

3.2 Portfolio mode operation strategy comparison.

Through the comparison and analysis of the sections, it can be concluded that the advantages and disadvantages of the eight operating modes of the ASHP, solar and capillary heating system, and also the corresponding architectural types. The following features of the eight operating modes are summarized, as shown in table 3-2.

Table 3-1. The operation features of each mode

Mode	advantage	Shortcoming
Mode 1	The indoor temperature is high throughout the day, which ensures the night heating and makes good use of air energy and solar energy.	The collector has low thermal efficiency and high energy consumption.
Mode 2	To meet the requirement of high daytime temperature and low nighttime demand, the temperature is high in the night, so that the capillary tube will not be heated in the morning and consume less power.	Less heat-collecting efficiency of Solar collector and less heating time at night.
Mode 3	The heating efficiency of collector is higher, and the indoor temperature can be guaranteed during the day.	The system energy consumption is higher, the temperature difference between night and night is large, the night system is not stable, and the indoor temperature is not guaranteed.
Mode 4	The efficiency of the collector is higher, and the indoor heating quantity is guaranteed. The indoor temperature difference between day and night is small, and the thermal comfort is relatively high.	Night air source heat pump system frequently defrost, operating instability.

4. Conclusion

This paper compares and analyses different modes of solar auxiliary ASHP radiant heating system through measurement and simulation, and presents different heating operation strategy for different buildings. The specific results are as follows:

In the solar auxiliary ASHP, solar hot water replaces the low temperature heat source of the heat pump cycle in outdoor evaporator, which can better utilize the solar energy collection heat capacity. Heat pump system can stable operation, the indoor temperature with small fluctuations basic keep at around 20℃; In low temperature capillary radiant heating system, capillary water temperature can meet the demand of indoor heating when it is higher than 28℃. Indoor temperature kept at around 18℃ and the body feeling temperature is 20-21℃, where temperature field is even and the thermal comfort is higher. In the cycle of solar hot water participation, the system is generally energy-saving, stable, reliable and efficient. The operating modes of various combination systems have their own characteristics, so different combinations should be used for indoor heating for different buildings.

In the solar auxiliary ASHP, with the help of solar water, the ASHP system can stabilize the heating. The combined operation mode of ASHP solar capillary radiant heating system has advantages and disadvantages. Different heating strategies should be selected according to the non-function of buildings. But more energy efficient way is to as much as possible to heat by using low temperature capillary radiant heating system (water temperature greater than 28℃). When it cannot meet the requirements, the low temperature water can be used to heat the solar auxiliary ASHP system (Water temperature above 10℃). Finally, the single ASHP system is selected.

Acknowledgments

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