STUDY ON OPERATING CHARACTERISTICS OF AIR SOURCE AIR SOURCE HEAT RECOVERY HEAT PUMP UNIT IN WINTER

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Abstract：Based on the principle of air source heat pump with condensing heat recovery introduced in this paper, the operating performance of the system in winter is analyzed. According to the characteristics of this kind of heat pump system and the experimental results, a optimal operating mode is presented: to match the requirements of air conditioning heating load in winter and when temperature of the hot water tank is below 45°C, the domestic water should be heated.

Keywords：**air-source heat pump; operating mode in winter; condensing heat recovery; domestic hot water temperature**

1 INTRODUCTION

Air conditioning systems consume energy at the cost of releasing a lot of condensing heat into the atmosphere, which causes thermal pollution to the atmosphere and intensifies the urban heat island effect. Preparation of domestic hot water needs to consume primary energy. It is a question that how to reduce emissions of condensing heat and the energy consumption in the production process of domestic hot water. People are paying more and more attention to heat recovery technology. The condensing heat can be used to produce hot water. This technology has been used in engineering, and achieved benefits [1]-[3].
Research on air-conditioning chillers for condensing heat recovery in developed countries has been comparatively more perfect and related products were in application. Experimental study on condensing heat recovery technology of room air conditioner has been put forward in Nanyang Technological University[4]. University of Science and Technology of China proposed an air conditioner integrated water heater which could separately realize hot water supply mode, cooling and water heating mode and heating mode[5]. Experimental study on energy-saving air-conditioner with domestic hot water supply was carried out in Harbin Institute of Technology[6].
The research in China was mainly focused on the transformation of small-scale household air conditioning system and condensing heat recovery for large-scale system was often more involved in the transformation of large-scale chillers. Study on condensing heat recovery technology for large-scale air-source heat pump, especially experimental study, is very little [5]-[7]. This paper uses domestic theoretical and experimental results of small-scale household multi-function heat pump air-conditioner integrated water heater as reference, so as to do research on principle and operating mode of the large-scale air-source heat pump with condensing heat recovery and also experimental study on the performance characteristics of the prototype.

2 SYSTEM PRINCIPLE AND OPERATION MODE

Based on heat pump technology and condensing heat recovery technology[8]-[10], air-source heat pump system was improved in this paper. The new system used compound condensing method of air-cooling and water-cooling technology in place of single air cooling method. So it had the functions of air conditioning heat pump and water heater. Through a reasonable design, the two functions run in a coordinate way to get multi-function heat pump system integrated air-conditioner and water heater, the principle as shown in Figure 1.

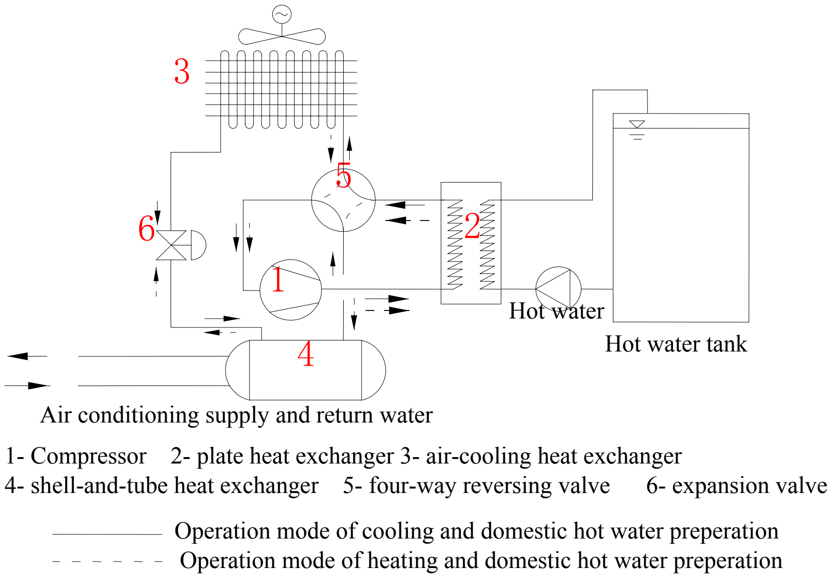


Fig1：principle of heat pump with condensing heat recovery

Such heat recovery heat pump cycle can be showed on the p-h figure, as shown in Figure 2.

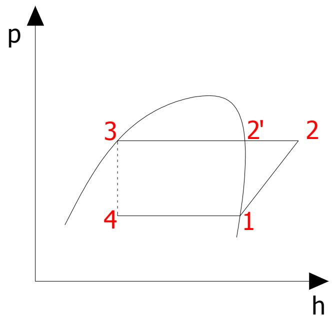


Fig2：theoretical cycle diagram of heat pump system with condensing heat recovery

For the theoretical cycle, refrigeration vapor leaving evaporator is saturated vapor under evaporative pressure; liquid leaving condenser coils is saturated liquid under condensing pressure; process in compressor is isentropic compression; enthalpy of refrigerant before and after passing the expansion valve is equal; pressure of refrigerant in evaporation and condensation process is constant and the state of refrigerant does not change in connected pipes of different device; condensing temperature of refrigerant is equal to ambient temperature and evaporation temperature is equal to the temperature of the air conditioning water used as the secondary refrigerant.
Such heat pump system has characteristics of multi-function and full-year running. There operation modes can be achieved by switching control elements: mode of cooling and preparing domestic hot water in summer, mode of heating and preparing domestic hot water in winter and of cooling (or heating) and hot water preparation in transition seasons. The

object of study is the operation mode of heating and preparing domestic hot water in winter. The function of such heat pump system is different from common one, so the coefficient of performance of the system was redefined in this paper for analysis purposes.

①Coefficient of performance of air conditioner: COP_a

$$COP_a = \frac{Q_h}{N}$$

where:

Q_h is air conditioning cooling (heating) capacity

N is input power of whole system

②Coefficient of performance of domestic hot water: COP_w

$$COP_w = \frac{Q_w}{N}$$

where:

Q_w is domestic hot water heat gain

N is input power of whole system

③Comprehensive coefficient of performance COP_{a+w}

$$COP_{a+w} = \frac{Q_t}{N}$$

where:

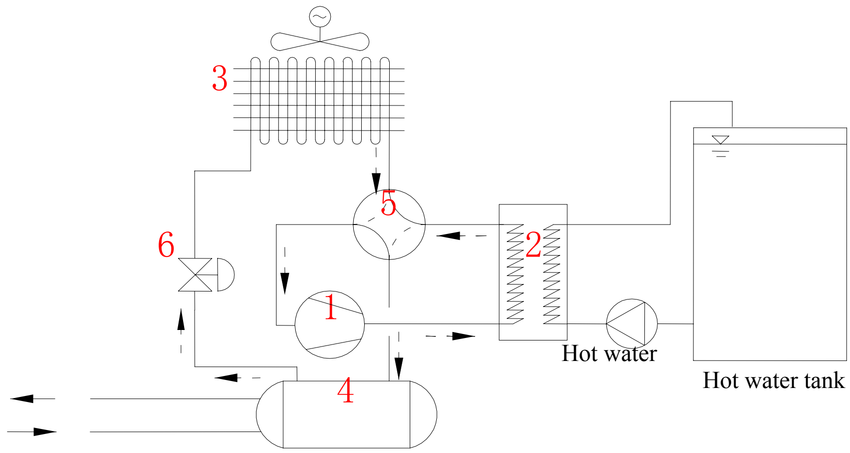
Q_t is air conditioning cooling (heating) capacity + domestic hot water heat gain

N is input power of whole system

3 OPERATION MODE OF HEATING AND PREPARING DOMESTIC HOT WATER IN WINTER

In winter, the heat pump system should match air-conditioning heating load and also prepare domestic hot water through the plate heat exchanger. Four-way reversing valve of the system was at the state of heating. When in the mode of air conditioning heating and domestic hot water preparation, principle of the system is shown in Figure 3, the flow direction of refrigerant shown by the arrow.

When the system was operating, low-pressure working vapor was pressurized by the compressor and became high-temperature and high-pressure gas. The gas first entered the plate heat exchanger, in which the temperature of the gas is decreased and then it heated the domestic water. Then it enter the shell-and-tube condenser (evaporator in summer), furthermore is condensed and heat air conditioning water. Subsequently through the expansion valve into the outdoor evaporator (condenser in summer), the gas absorbed heat from the environment and evaporated to low-pressure gas. Then the gas entered the compressor again to complete a cycle.



Air conditioning supply and return water (45/40°C)
1- Compressor 2- plate heat exchanger 3- air-cooling evaporator
4- shell-and-tube condenser 5- four-way reversing valve 6- expansion valve

Fig3：principle of heat pump with condensing heat recovery in winter

As condenser used for heating air conditioning water was connected behind the plate heat exchanger, the plate heat exchanger used part of condensing heat for water heating, but in fact sacrificed some amount for indoor heating to meet domestic hot water heating demand. In winter when outdoor temperature is lower, indoor heat load is raised, which will result in insufficient heat for air conditioning and poor indoor heating effect. To ensure indoor heating effect, the condensing temperature should be higher than the design temperature (45℃) of air conditioning supply water. Therefore, the amount of condensing heat during that domestic hot water absorbed, as well as the temperature of domestic hot water entering the plate exchanger must be well controlled. As shown in Figure 4, the condensing heat consists of two parts: heat generated in superheat region and heat generated in two-phase region.

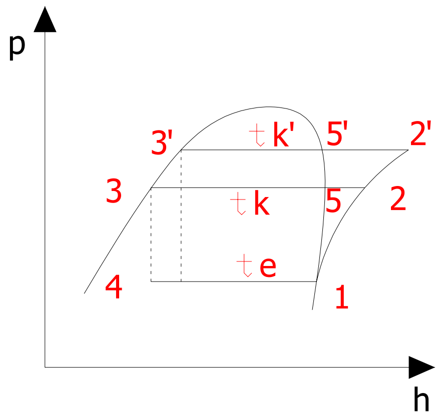


Fig. 4. theoretical cycle diagram of condensing temperature change

When the condensing temperature is increased from t_k to t_k’, the total condensing heat is changed from h_2-h_3 to $h_{2'}$-$h_{3'}$. Of which, the heat $h_{5'}$-$h_{3'}$ generated in two-phase region decreased compared with h_5-h_3, while the heat $h_{2'}$-$h_{5'}$ generated in superheat region increased compared with h_2-h_5. This was mainly caused by the sensible heat exchange in superheat region significantly influenced by temperature difference. When the condensing temperature is increased, there would be a sharp rise of the compressor’s exhaust temperature. Then heat generated in superheat region increased with the rise of temperature difference of refrigerant between the inlet and outlet.
Taking R22 for an example, calculated the condensing heat where the evaporating temperature was 0℃and the condensing temperatures were 50℃, 55℃ and 60℃, respectively. The results are shown in Table 1.

Table 1： Condensing heat at different condensing temperature

Evaporating temperature(℃)	Condensing temperature (℃)	Total condensing heat (kW)	Condensing heat generated in superheat region (kW)	Condensing heat generated in two-phase region (kW)
0	50.0	60.3	15.9	44.4
0	55.0	58.9	18.0	40.9
0	60.0	57.6	20.3	37.3

Air conditioning heating and domestic hot water preparation process both needed to use the condensing heat in winter. Because some condensing heat was used to heat domestic hot water, the heat for air conditioning would be less. When the domestic hot water temperature was below the design temperature(45℃) of air conditioning supply water, it might lead to lower condensing temperature of the heat pump system. Then the air conditioning water temperature decreased and would be even lower than the design temperature. Therefore, in order to ensure air conditioning heating effect, the inlet (inlet of the plate exchange) temperature of domestic hot water should not be lower than the design temperature of air conditioning hot water. At the same time, the condensing temperature (usually determined by the temperature of air conditioning supply water) remained the same, the plate heat exchanger used for domestic hot water heating could only absorb condensing heat generated in superheat region, while the heat exchanger used for air conditioning water heating absorbed heat generated in two-phase region only. The ratios of air conditioning heat capacity and domestic hot water condensing heat gain at different condensing temperature were shown in Table 2.

Table 2：the ratios of condensing heat for air conditioning and for domestic hot water heating

Condensing temperature (℃)	The ratio of air conditioning heat capacity and domestic hot water heat gain
50.0	2.79
55.0	2.27
60.0	1.84

4 CONTROL STRATEGIES FOR OPERATION MODE OF SYSTEM IN WINTER

In winter, the system had to provide heat for air conditioning heating and domestic hot water heating. Because some condensing heat was absorbed through the plate exchanger, the heat for air conditioning would be less. If the hot water inlet temperature was set too low, it might cause that the temperature of air conditioning supply water could not achieve the design value. Therefore, according to the hot water temperature meeting the air-conditioning requirements, the initial temperature of domestic hot water heating should be set reasonably. When the temperature of domestic water tank was below the set temperature, the water circulating pump between the heat pump system and water tank should start to work and the domestic hot water would be heated.

5 EXPERIMENTAL STUDY ON OPERATION MODE OF SYSTEM IN WINTER

Experiments were carried out on this type of air-source heat pump system for condensing heat recovery in different operating conditions with a test device.

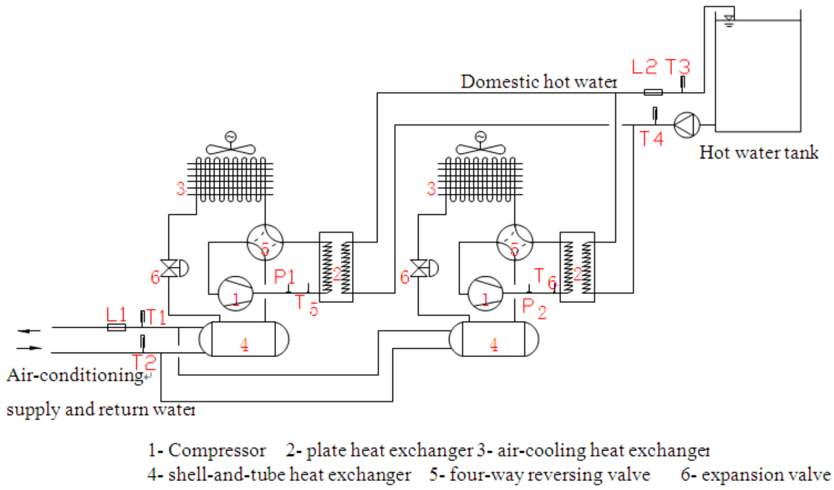


Fig5：Principle of experimental system

As shown in Figure 5, experimental system consisted of two air source heat pump systems with heat recovery in parallel. The main parameters were shown in Table 3.

Table 3：Nameplates of experimental system

Compressor	Screw compressor
Refrigerant	R22
Rated cooling capacity（kW）	400
Rated heating capacity（kW）	450
Rated power（kW）	120

The test methods of this experimental study took regulations of GB/T10870-2001 "The methods of performance test for positive displacement & centrifugal water-chilling units and heat pump" as reference. The outdoor parameters referred to heat pump testing standards. The demand of cooling capacity and heating capacity for air conditioning was achieved by secondary refrigerant heat balance method. Domestic hot water driven by circulating pump was heated circularly between the plate heat exchanger and the water tank. In this experiment the situation that hot water might be used or consumed was not considered during process of domestic hot water heating (volume of the hot water tank:10m^3).
When the ambient air temperature was 7°C, with the domestic hot water temperature changing, the condensing heat gain of domestic hot water, coefficients of system performance and the temperature of air-conditioning supply and return water were tested (see Figure 6~8) in the experiment.

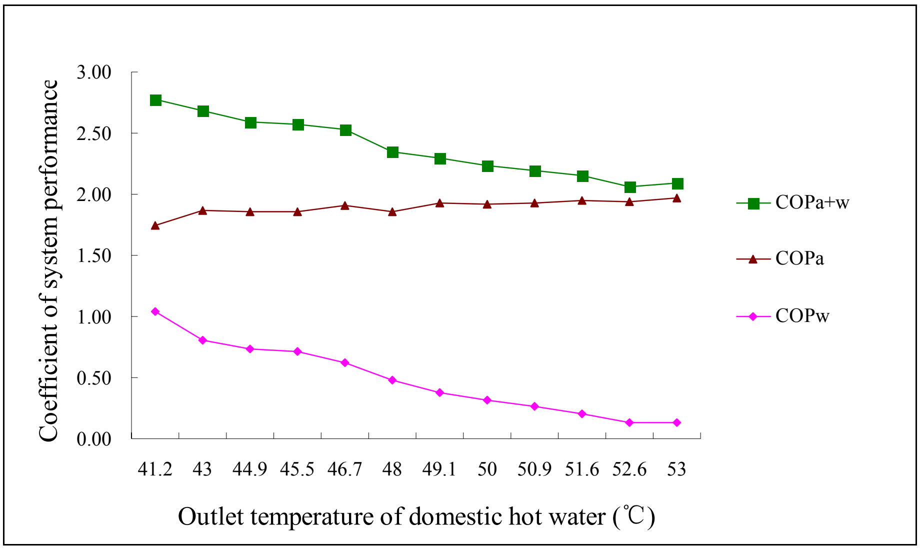


Fig 6：system performance curve in winter

As shown in Figure 6, in winter, with rise in the outlet (outlet of plate exchanger) temperature of domestic hot water, the coefficient of performance of domestic hot water decreased. COP_w ranged from 1.04 to 0.13, average value of 0.5. Especially when the outlet temperature achieved 55℃, the value of COP_w was only 0.2. It shows that the coefficient of performance of domestic hot water is relatively low in winter and on the premise of meeting the needs of air conditioning heating, the outlet temperature of domestic hot water is hard to exceed 55°C. With rise in the outlet temperature of domestic hot water, the coefficient of performance of air conditioner increased. This was mainly the reason that as the domestic hot water temperature rose, the plate heat exchanger absorbed less condensing heat, while the shell and tube heat exchanger absorbed more, in other words, heat gain of air conditioner side is increased. COP_a ranged from 1.74 to 1.97, average value of 1.89. The comprehensive coefficient of performance decreased with the outlet temperature of domestic hot water increasing. This was due to that the increment of air conditioning heat gain was less than the decrement of domestic water heat gain.

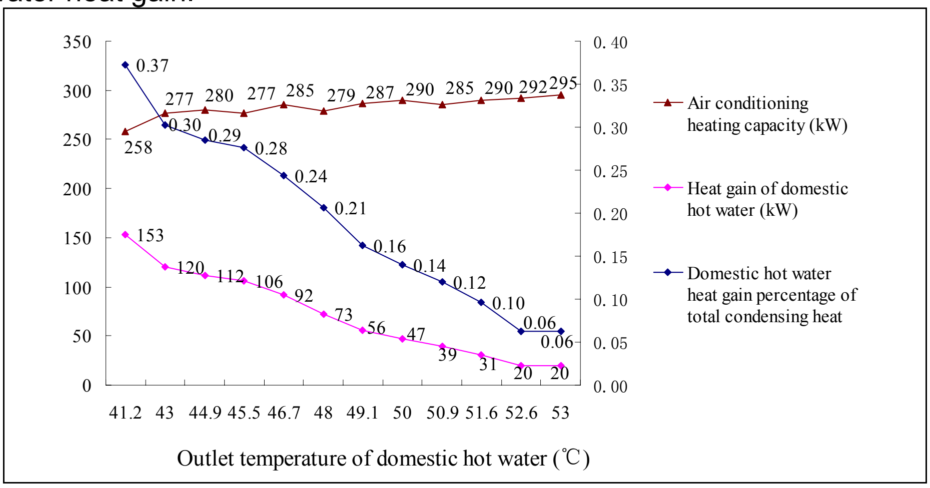


Fig7：air conditioning heating capacity and heat gain of domestic hot water changes with the water temperature in winter

The domestic hot water and air conditioning hot water were both required to be heated, so the domestic hot water heating would directly relate to the air-conditioning heating effect. As shown in Figure 7, in winter, when the domestic hot water temperature was heated from 41.2 °C to 53°C, the condensing heat gain of domestic hot water side accounted from 37% to 6%

of the total condensing heat with an average value of 19%. This was mainly because when the inlet temperature of domestic hot water was higher than the system condensing temperature, the domestic hot water absorbed heat generated only in the superheat region. And then as the domestic water temperature increased, the temperature difference of heat exchange became smaller and so as to the domestic water heat gain percentage of total condensing heat.

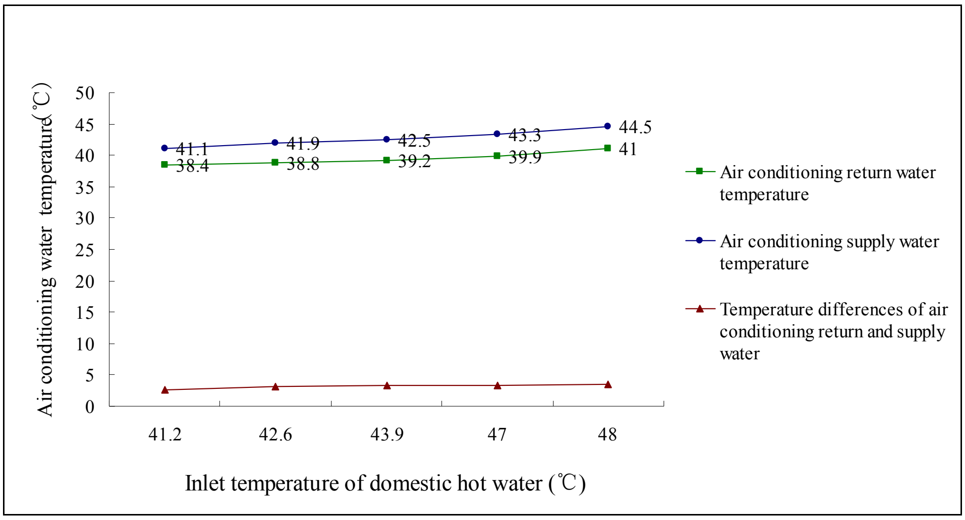


Fig8：water temperature curve of air conditioner in winter

Based on the experimental results (Figure 8), the temperature of air conditioning supply and return water decreased as the inlet (inlet of plate exchanger) temperature of domestic hot water fell down. When the inlet temperature of domestic hot water fell below 45℃, the temperature of air conditioning supply water would be below 44℃. This was mainly because that: when the temperature of domestic hot water was low, the amount of condensing heat absorbed by plate heat exchanger exceeded the condensing heat generated in superheat region at the system design condensing temperature (generally 50℃), which might cause the decreasing of system condensing temperature (lower than 50℃). And then it leaded to the air conditioning supply water temperature below the design value (45℃), which would affect indoor heating. Therefore, when operating in winter, the set inlet temperature of domestic hot water should not be lower than 45 ℃ and when temperature of the domestic hot water tank was below 45 ℃, the circulating pump between unit and water tank should start to work and the domestic hot water would be heated.

6 Conclusions

Through the theoretical analysis and experimental research, the following results could be concluded:

1） When operating in winter, to meet the heat requirements of air conditioner side, the temperature of domestic hot water in water tank should not be set below 45℃.

2） In winter, the efficient of performance of domestic hot water was generally low, with an average value of only 0.5, and the condensing heat gain of domestic hot water accounted for only 19% of the total condensing heat.

3） Based on the research results, when operating in winter, according to the temperature of supply domestic hot water and the demand of heating capacity, decide that the auxiliary heat equipments are necessary or not for domestic hot water heating.

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