THERMODYNAMICS ANALYSIS AND THERMOECONOMICS EVALUATION ON HEAT REVOVERY INVERTER AIR-COOLING HEAT PUMP WITH DOMESTIC HOT WATER

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ABSTRACT

In recent, the technique of the heat pump system that can provide domestic hot water have widely developed, because this heat pump system can not only decrease quantity of heat letting to the environment from the air-conditioning system and enhance the performance(such as:EER) of heat pump system but also supply hot water to the family life.

Two different schemes have been brought out in previous researches. But both of them can not normally work in the cold winter.

This paper addresses a new scheme of heat recovery heat pump system that can operate all-year-round. The thermodynamics analysis and the thermoeconomics evaluation are also executed in it. From the analysis and calculation results, we can find that this new system can improve the thermodynamic cycle greatly, increase the EER of the system, save the operation cost, and decrease the thermal pollution to the environment.

1. INTRODUCTION

In the conventional heat pump system, the condensation heat is exhausted to the outdoor surroundings vainly, which not only engenders energy wasting, but also yields thermal pollution to the outdoor environment. The proper recovery of waste condensation heat to produce domestic hot water is a kind of efficient means of comprehensive energy utilization. To a modern urban family, domestic hot water is necessary for daily life, and is usually provided by a domestic water heater making use of electricity or gas, which is well known for its great energy squander.

Therefore, the development of a heat pump system with domestic hot water is of great potential to save energy.

There are a great number of research papers and patents on this technique [1, 2, 3]. To realize the recovery of condensation heat to produce domestic hot water, all the research works focus on the following two schemes: (1) to use the water-cooling condenser to replace the air-cooling condenser; (2) to add a desuperheater at the outlet pipe of the constant speed compressor. For scheme 1, the system can operate normally in refrigeration mode. While in winter, the room needs to be heated, thus, the water-cooling heat exchanger acts as an evaporator, and the water in it is cooled by the refrigerant and may freeze. So this kind of system cannot operate in winter. Therefore in winter, some other equipment is needed to heat the room and to supply domestic hot water. The whole system becomes more complex, and both the occupied space and the equipment initial cost increase significantly. For scheme 2, the system can operate in winter. But, because the system has to supply hot water for room heating system and domestic hot water at the same time, and the speed of the compressor is constant, some problems may occur during the operation period. For example, the heat supply may be insufficient; the flow rate of the domestic hot water may be smaller than required; and the temperature of the domestic hot water may be too low to use.

2. CONFIGURATION AND PRINCIPLE OF THE NEW SYSTEM

A new scheme of inverter air-cooling heat pump system with domestic hot water is presented in this paper. Two water-refrigerant heat exchangers are equipped in the air-cooling heat pump system. One, called water reheater, is placed between the compressor outlet and the four-way valve inlet. And the other, called water preheater, is between the condenser and the throttling device. This scheme is designed to utilize the sensible heat of superheated gas exhausted from compressor and that of the subcooled liquid flowing out of the condenser. With these two parts of heat, the water can be heated to a temperature high enough for domestic use. Such a scheme can not only utilize the waste condensation heat to a top limit, but also improve the system performance since the liquid refrigerant into the throttling device is subcooled deeply.

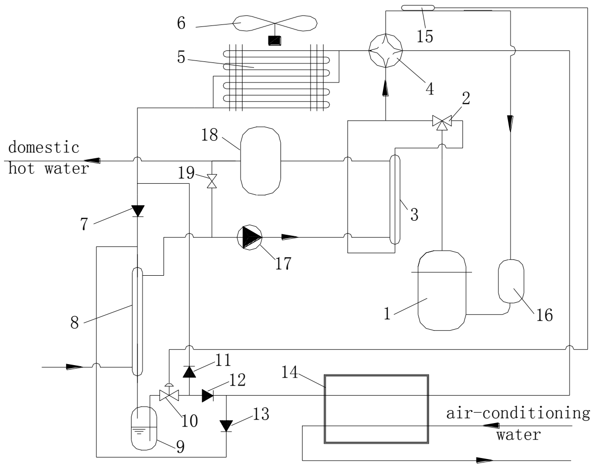

Figure 1 Configuration of the System

1---compressor, 2---three-way valve, 3--reheater, 4-- four-way valve, 5---air heat exchanger, 6---fan, 8---preheater, 9---receiver tank, 10---thermal expansion valve, 14--water heat exchanger, 15---temperature sensor, 7,11,12,13---check valve, 16---gas-liquid separator, 17---domestic water pump, 18---domestic water tank, 19---valve

Considering of part load conditions at most of the time, an inverter compressor is adopted as the substitute of the constant one used in the conventional heat pump system. The excellent ability of adjusting capacity can keep the system working at high efficiency in the period of part load.

To reduce the peak load of the system, a hot water storage tank with a circulation pump is placed in the system. When the domestic hot water is not in use, the water in the tank is sent by the pump to be heated and stored in it. This scheme can solve the problem of insufficient heat supply in winter condition to some extent.

3. SYSTEM PERFORMANCE

This system can operates in five modes: cooling only, heating only, hot water only, cooling with hot water, heating with hot water. The operating configurations of cooling only mode and heating only mode like usual heat pump system; The operating configurations of the other three modes are showed in Figure 2, Figure 3, and Figure 4, respectively.

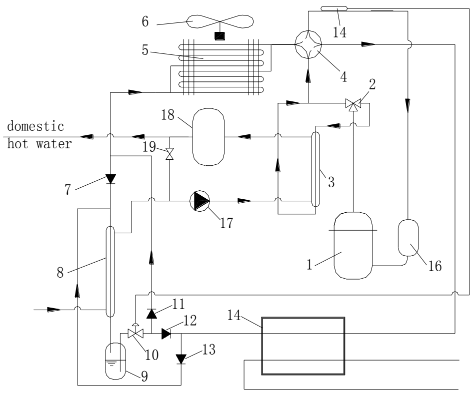

Figure 2 Domestic Hot Water Only Mode

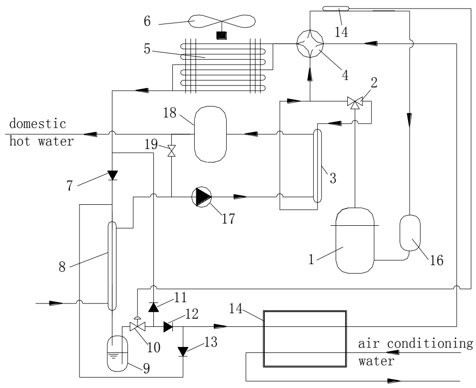

Figure 3 Cooling with Domestic Hot Water

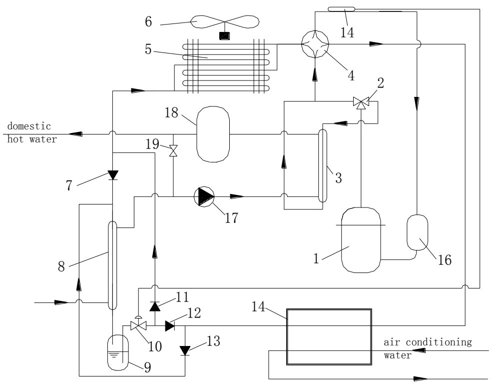

Figure 4 Heating with Domestic Hot Water

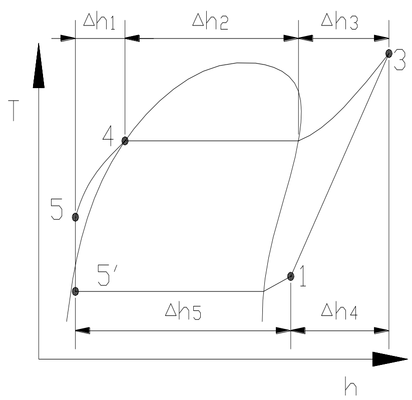

Figure 5 Cycle in T~h Diagram

3.1 Improvement on Thermodynamic Cycle

The thermodynamic cycle of the system is shown in Figure 5. The system improves the thermodynamic cycle from two ways. One is the installation of reheater, which not only decreases the compressor discharging temperature, but also increases the domestic water temperature. Because the compressor discharging temperature is very high, the domestic water can be heated to a satisfied temperature not by raising the condensing temperature. The other is the installation of preheater which enlarge the subcooling degree. Thus both Δh_1 and Δh_5

are increased.

3.2 Energy Efficiency Ratio

Energy efficiency ratio (EER) is an important parameter to evaluate the system performance. In this kind of heat pump system, EER can be expressed as

$$EER = \frac{\sum Q}{\sum W} = \frac{Q_{water} + Q_{room}}{\sum W} \tag{1}$$

In the hot water only mode, heating only mode and heating with hot water mode

$$EER = EER_1 = \frac{\Delta h_1 + \Delta h_2 + \Delta h_3}{W} \tag{2}$$

In the cooling only mode, $EER = EER_2 = \dfrac{\Delta h_5}{W}$ (3)

In the cooling with hot water, $EER = EER_3 = \dfrac{\Delta h_1 + \Delta h_3 + \Delta h_5}{W}$ (4)

EER_1 and EER_2 are the same as the traditional heat pump systems. The most benefit of this system is that the condensing heat is turned to be useful when it operates in cooling with hot water mode.

Based on the above definitions of EERs in different modes, the operation performances of Cooling Only mode, Cooling with Hot Water (CHW) mode, Heating Only mode and Heating with Hot Water (HHW) mode have been calculated by computer. The calculational working conditions are shown in Table 1.

Table 1 Calculational working conditions

Items	CHW	HHW
Outdoor dry bulb temperature	35°C	7°C
Outdoor wet bulb temperature	24°C	6°C
Inlet air conditioning water temperature	12°C	40°C
Outlet air conditioning water temperature	7°C	45°C
Inlet hot water temperature	15°C	15°C
Outlet hot water temperature	45°C	45°C

Figure 6 shows the calculation results of EER in cooling with domestic hot water mode and cooling only mode. From the figure we can see that when the system operates in cooling with domestic hot water mode, the EER is about 0.9 higher than that in cooling only mode. This is mainly because of the

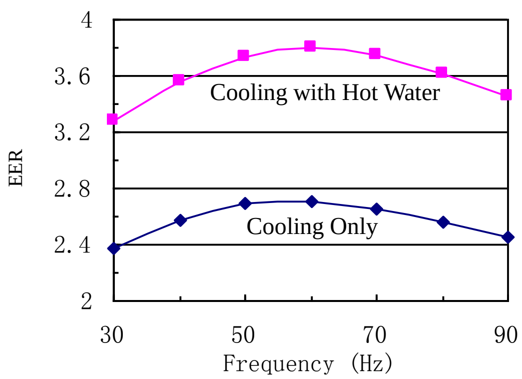

Figure 6 EER in Different Modes

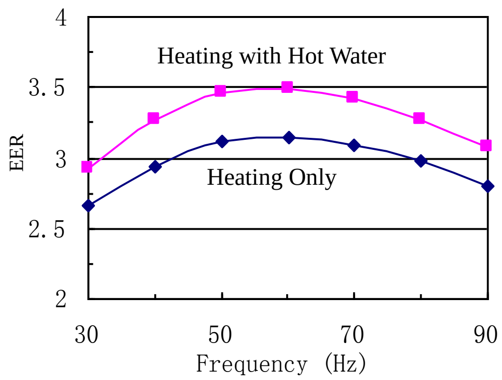

Figure 7 EER in Different Modes

preheater and reheater. The reheater absorb part of the heat of gaseous refrigerant at the outlet of the compressor, then the condensation temperature is reduced, so the EER of the system is higher than conventional system. The preheater increases the super-cooling degree and enlarges the useful enthalpy difference, and refrigerating capacity is higher than before.

From Figure 7, we can find that EER is 0.3 higher in heating with hot water mode than in heating only mode. This is mainly also caused by the preheater and reheater. The domestic hot water decreases the subcooling degree and enlarges the useful enthalpy difference. Thus more energy comes to application with same input energy. So EER rises and the performance is improved. This is the superiority of this system to the traditional heat pumps.

3.3 Comparison on Thermoeconomics

Thermoeconomics is the product of combination of thermodynamic analysis and economic factors. A product which can come into use is not only good in theory but also has good ratio of performance to price. EER in thermoeconomics can be expressed as

$$EERc = \frac{\sum Q_i C_i}{\sum W_j C_j + \sum \eta_k C_k} = \frac{Q_{water} C_{water} + Q_{room} C_{room}}{\sum W_j C_j + \sum C_k} \quad (5)$$

Where: C-----the price of each one C_k---the initial cost converted to each year

In order to evaluate the performance of this system, a house about 190m^2 in Beijing is taken for an example to analyze. The comparison results of the cost of several systems are shown in Table 2. In the calculation, the price of electric power is 0.39¥/(KWh), and the gas is 1.5¥/(m^3)

The other systems need a single water heater driven by electricity of gas. Compared with the other systems, the inverter air-cooling heat pump system with domestic hot water can save a lot of money for the user every year. Although the system air conditioners with gas water heater is nearly the same with this system on the cost, but this system is much better on the aspects such as safety, stability, low thermal pollution and so on.

Table 2 Thermoeconomics Comparisons of Different Systems

			Cool/hot ACHP	VRV	Air Conditioner	Inverter ACHP with Domestic Hot Water
EER	Cooling only		2.7	2.9	2.8	2.7 3.5(with water)
	Heating only		3.1	3.3	3.2	3.1
Initial Cost	AC system (¥)		39000	120000	25000	40000
	Water heater (¥)		3000	3000	3000	0
	Total (¥)		42000	123000	28000	40000
	C_k (¥/year) (for 10 years)		4200	12300	2800	4000
Operating Cost	Cooling (¥/year)		1010	940	970	1010
	Heating (¥/year)		4890	4590	4730	5500
	Hot Water	Electric (¥/year)	5080	5080	5080	380(hot water only)
		Gas (¥/year)	2380	2380	2380	
	Total	Electric (¥/year)	10980	10610	10780	6890
		Gas (¥/year)	8280	7910	8080	
Total	Electric(¥/year)		15180	22910	13580	10890
	Gas(¥/year)		12480	20210	10880	

4. CONCLUSIONS

In this paper, a scheme of inverter air-cooling heat pump system with domestic hot water is presented, and the thermodynamics analysis and the thermoeconomics evaluation are executed on it. From the analysis and calculation results, we can find that this system can improve the thermodynamic cycle greatly, increase the EER of the system, save the operation cost, and decrease the thermal pollution to the environment.

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