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Experimental investigations of two types of the dual-loop heat pump systems for ventilation heat recovery

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Abstract

Heat recovery capability of ventilation system can be effectively improved by using multiple loop independent heat pump cycles. This paper focus on how to further improve the performance in the heat pump system under constant loop number and compressor displacement. The heat recovery performance differences between two types of the dual-loop heat pump system were compared through experimental testing. Results show that COP of the system in which the displacement in the low-pressure loop is twice of that in the high-pressure loop can be increased by 14.78% comparing with the system in which the displacement in the low-pressure loop is half of that in the high-pressure loop. Especially, the COP of the former system is even higher than that of the triplex loop heat pump system under some operating conditions. Therefore, in multi-loop heat pump system for ventilation heat recovery, it is more significant to increase the circulating flow rate of the working fluid in low-pressure loop.

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Keywords: heat pump ; ventilation heat recovery ; dual loop; displacement ratio

1. Introduction

According to statistics, the energy consumption of buildings accounts for more than 40% of the total energy consumption in the European Union [1]. As the largest developing country in the world, the energy consumption of civil buildings accounts for about 25% of the total energy consumption in China [2]. Reducing the building energy consumption caused by ventilation system is an effective way to reduce building energy consumption [3-4]. Relevant studies have also confirmed that heat recovery from indoor exhaust air can greatly reduce the energy consumption of buildings [5-6].

The recovery efficiency of heat pump heat recovery system can reach 100% [7]. Some scholars have analyzed the energy-saving buildings using heat pump for ventilation heat recovery, and considered that the heat pump system has excellent performance, and the heat pump system has a better application prospect for ventilation heat recovery [8-9]. However, with the decrease of outdoor temperature in cold climate, the circulating mass flow rate of refrigerant will gradually decline in the heat pump system, and the excessive attenuation of circulating mass flow rate is not conducive to the heat recovery of exhaust air. Therefore, in order to improve the performance of the system at low outdoor temperature, some scholars have proposed a solution of multi-loop compression cycle [10].

The multi-loop heat pump ventilation heat recovery system proposed in reference [10] has excellent heat recovery performance with the same compressor displacement in each loop. Whether the displacement distribution of loops has influence on the performance of the system has not been studied. Therefore, this paper proposed two kinds of dual-loop heat recovery system. The total displacement of the compressors in the two systems is the same, but the displacement ratio in the high- and low-pressure loop is different. The performance

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of different dual-loop systems is analyzed by experiments, and the difference of displacement ratio for influence the performance of system is summarized and analyzed.

2. Method

2.1. System principle

Compressors A, B and C with the same specifications were used for experiments. Dual-loop system I represents a dual-loop system with a displacement ratio of 2 between high- and low-pressure loop, the system scheme is shown in Fig. 1. Compressors A and B were connected in parallel in the original experimental platform, so that the displacement in the high-pressure loop was twice as large as that in the low-pressure loop. At the same time, heat exchanger # 1 and # 2 were paralleled used as the condenser of high pressure-loop, heat exchanger # 4 and # 5 were used as the evaporator of high-pressure loop. Low-pressure loop was driven by compressor C. Heat exchanger # 3 and # 6 were used as condenser and evaporator of low-pressure loop, respectively. The low-temperature outdoor fresh air first passed through the low-pressure loop composed of compressor C, and then heated by the high-pressure loop composed of compressor A and B in parallel, finally sent into the indoor.

Dual-loop system II represents a dual-loop system with a displacement ratio of 0.5 between high- and low-pressure loop, the system scheme is shown in Fig. 2. The low-pressure loop was driven in parallel by the compressors B and C. At the same time, the heat exchangers # 2 and # 3 were used as the condenser of the low-pressure loop, the heat exchangers # 5 and # 6 were used as the evaporator of the low-pressure loop. High-pressure loop was driven by compressor A. Heat exchangers #1 and # 4 were used as condenser and evaporator of high-pressure loop, respectively. The low-temperature outdoor fresh air first passes through the low-pressure loop composed of compressors B and C, and then heated by the high-pressure loop composed of compressor A, finally sent into the indoor.

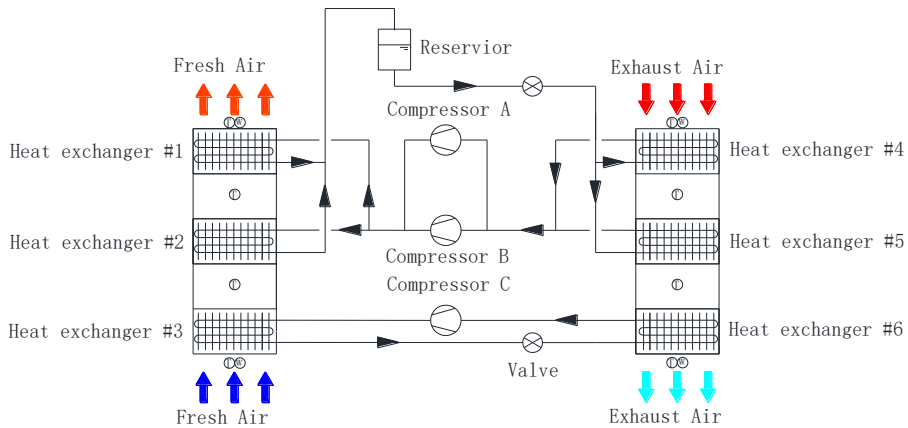


Fig. 1. Dual-loop system I: Displacement ratio between high-pressure loop and low-pressure loop is 2.

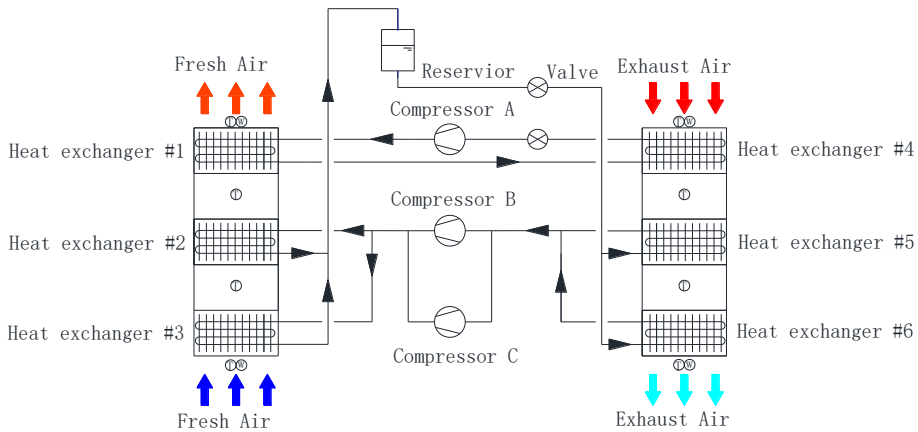


Fig. 2. Dual-loop system II: Displacement ratio between high-pressure loop and low-pressure loop is 0.5.

Fig. 3 is the representation of dual-loop heat pump ventilation heat recovery system on P-h diagram. The dual-loop system on the P-h diagram is composed of two independent cycles. A1-A2-A3-A4-A1 stands for low-pressure cycle, B1-B2-B3-B4-B1 stands for high-pressure cycle. There is no heat or mass exchange between the two cycles.

When the relatively low-temperature fresh air first enters the condenser of the low-pressure loop, the condensing pressure of the loop is lower because of the low air temperature. The air is gradually heated when flowing through the condensers. When fresh air entering the condenser of the next loop, the air temperature is already high. So the condensing pressure of this loop is higher than that of the low-pressure loop. When the exhaust air with high temperature enters the evaporators, the evaporating pressure of the loop which contact exhaust air first will relatively high, and then the evaporating temperature and evaporation pressure of the next loop are lower because the air has been cooled. This is the principle of the formation of high-pressure loop and low-pressure loop in dual-loop system. The two loops are combined in a step by step way to recover heat from exhaust air. C1-C2-C3-C4-C1 represents the system cycle in which the traditional heat pump ventilation heat recovery system works in a large temperature and pressure range.

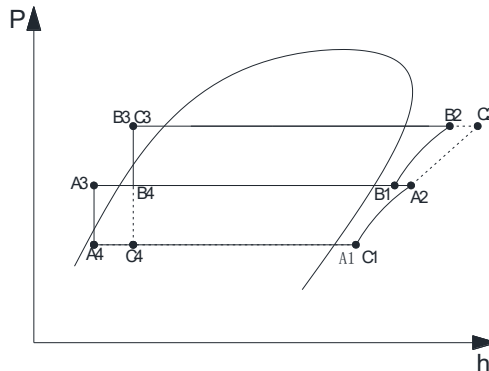


Fig. 3. P-h diagram of the dual-loop system cycle

2.2. Experimental procedure

Fig. 4 shows the photo of the experimental platform. The compressors used in the experiment are three GMCC rotary compressors of the same specification, the frequency is 50Hz, and the refrigerant used is R410A.

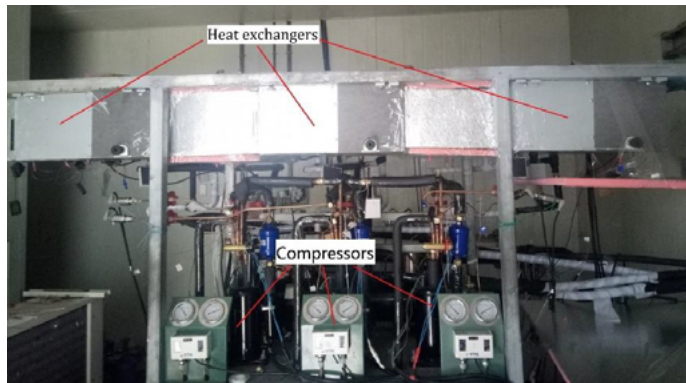


Fig. 4. Photo of the experimental platform

The fresh air heat exchangers (condensers) and the exhaust air heat exchangers (evaporators) of the experimental platform are respectively arranged in the outdoor environment simulation room and the indoor environment simulation room. The working environment of the ventilation heat recovery device can be realized by adjusting the temperature of the simulation rooms. The experimental test conditions are shown in Table 1.

Table 1. Test conditions

Test conditions	Indoor temperature (°C)	Outdoor temperature (°C)
Winter	20	15,10,5,0,-5,-10,-15,

3. Results and discussion

Fig. 5 shows the heating capacity changes for fresh air in different systems. From the point of view of the heating capacity to the fresh air, with the decrease of outdoor temperature, the heat obtained by the fresh air also increases gradually. The heating capacity of dual-loop system II is higher than that of dual-loop system I, which the growth amount can be up to 11.21%. That is, the heat recovery ability of dual-loop system II is higher than that of dual-loop system I. With the decrease of outdoor temperature, the fresh air temperature entering each heat exchanger is gradually declined. The temperature difference between the discharge temperature of the compressor and the fresh air temperature at the inlet of the condenser corresponding to the loop is gradually increased. The increase of the temperature difference between the refrigerant and the air will increase the heat transfer capacity of the heat exchanger to a certain extent. Therefore, with the decrease of outdoor temperature, the heating capacity of systems will gradually increase.

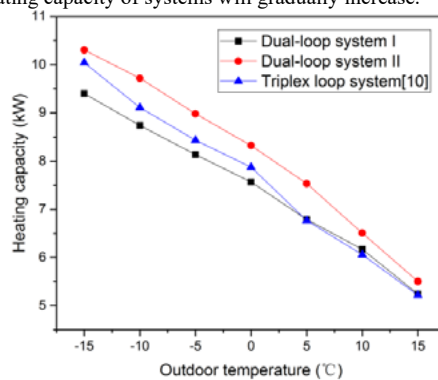


Fig. 5. Heating capacities of heat pump systems.

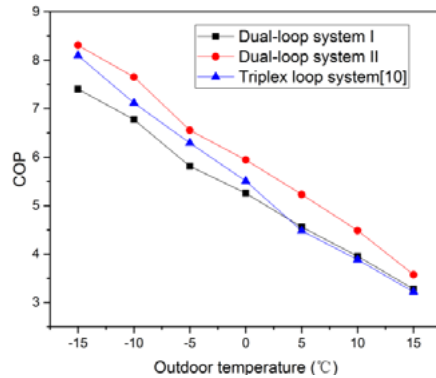


Fig. 6. COP of the heat pump systems.

The changes of system COP under each test condition is shown in Fig. 6. With the decrease of the outdoor temperature, the COP of the various systems are gradually increasing. The COP of dual-loop system II is higher than that of dual-loop system I at all test conditions, and the improvement can reach a maximum of 14.78%. The COP of the dual-loop system II is 2.61%~16.69% higher than that of triplex loop system as well. This is mainly because that the higher heating capacity and lower power input has been attained in dual-loop system II. This method to enlarge the displacement in the low-pressure loop can significantly improve the system performance while reducing the loop numbers and simplifying the composing for multiple loop heat recovery system as much as possible.

In general, heating capacity and COP of heat pump increase with increase of outdoor temperature, but the results of this study are opposite. This is actually the difference caused by the application of heat pump system in different occasions. When the heat pump system absorbs the heat from the low temperature outdoor air and then releases it to the high temperature indoor air, the heat source temperature in this condition is lower than the heat sink temperature. So the heating capacity and COP increase with the increase of the outdoor temperature. When the heat pump system is used for ventilation heat recovery, the system absorbs heat from the exhaust air (heat source) and then releases heat into fresh air (heat sink). In this application, the temperature of the heat source is higher than that of the heat sink in winter. Operating condition is just opposite to an ordinal heating condition, so the heating capacity and COP decrease with the increase of the outdoor temperature. Of course, this trend will change with the heat transfer limit of the device and the deterioration of the operating environment.

4. Conclusion

In this paper, based on the theory of multiple loop heat pump ventilation heat recovery system, the influences of two dual-loop systems with different displacement ratio on heat recovery performance were analyzed and compared by experiments, and the following conclusions were drawn:

(1) COP of dual-loop system with a displacement ratio of 0.5 in high- and low-pressure loop can be 14.78% higher than the dual-loop system with a displacement ratio of 2, and the heating capacity can be 11.21% higher.

(2) Compared with dual-loop system with a displacement ratio of 2 in high- and low-pressure loop, system performance in dual-loop system with a displacement ratio of 0.5 is better in system performance, which indicates that increasing the displacement ratio of the low-pressure loop is more beneficial to the performance improvement of the multiple loop system.

Acknowledgements

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