EFFECTS OF THE AIR VOLUME ON COOLING PERFORMANCE OF A REFRIGERATION SYSTEM

by

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In order to solve the problem of poor refrigeration performance during operation of the refrigeration system under low temperature conditions, this paper designs a refrigeration system test bench to study the effect of different air volumes on the cooling capacity of the refrigeration system under the conditions of 32 °C outside the warehouse and –10 °C inside the warehouse. The results show that when the air volume of condenser is set to 65% of the unit air volume and the air volume of evaporator is set to 100%, the cooling capacity of the system is 8.62 kW, the compressor power is 1.88 kW, the COP is 4.55 and the energy efficiency ratio is 1.64. In comprehensive consideration, this can not only ensure the best refrigeration performance but also can save considerable energy consumption.

Key words: *new style refrigeration system, air volume of condenser, cooling capacity, air volume of evaporator*

Introduction

With the development of living standards, the transportation and preservation of refrigerated food, drugs and other substances have an increasingly important impact on people's lives, but the cooling capacity of refrigeration systems often decreases under low temperature operation conditions. A fan is an important part of evaporators and condensers, the air volume of fans plays a vital role in the heat exchange effect of refrigerator systems, and the energy consumption of fans accounts for approximately 80% of the total energy consumption of the system. Therefore, studying the impact of condensing and evaporating air volumes on the performance of the system is very important for improving the energy saving effect and reducing energy consumption.

Many scholars have conducted relevant research. Okochi *et al.* [1] summarized the modeling and simulation of variable air volume (VAV) air conditioning system and used genetic algorithm to optimize some of them. The results were better than those of the traditional modeling method. Liu *et al.* [2] studied the factors that may affect the operation and energy consumption of heating ventilation and air condition (HVA) systems and found that the suction temperature of the compressor is directly proportional to the exhaust temperature, which is also related to the type of refrigerants and the compression ratio. He *et al.* [3] studied the change in enthalpy exchange efficiency of the total heat exchanger under different air volumes and found that for the same total heat exchanger, the greater the air volume is, the lower the enthalpy exchange efficiency, and the smaller the air volume is, the greater the enthalpy

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exchange efficiency. Zhang *et al.* [4] studied the influence of air volume on the heat transfer performance of a recirculation-type evaporator and found that under the condition of a large refrigerant supply, a fan with a large air volume is suitable, which is helpful to improve the heat transfer performance of the system. Li *et al.* [5] studied the effect of the air volume ratio on the performance of an indirect evaporative cooler and found that a lower outlet temperature, higher wet bulb efficiency, lower heat exchange and less water consumption can be obtained by adjusting the air volume. Jiang *et al.* [6] gave a theoretical analysis and practical performance of an innovative indirect evaporative chiller, tested indoor air conditions, with a room temperature of 23-27 °C and relative humidity of 50-70%. Duan *et al.* [7] showed that apparent acceleration in the water evaporation rate was gained from increasing inlet wet-bulb depression or air velocity, and the presented cooler showed a 31% increase in wet-bulb effectiveness and 40% growth in energy efficiency ratio (EER) compared to conventional indirect evaporative cooler. Rachapradit *et al.* [8] studied the performance of variable frequency split air conditioning under different refrigerant mass-flow, air volume flow and set point temperature. Xue *et al.* [9] studied the influence of different condensing air volumes on the operation characteristics of refrigerated containers and found that a decline in fan performance will reduce the condensing air volume of the condensing fan, thus increasing the cooling time and power consumption of the system. Hussain *et al.* [10] experimentally studied the performance of evaporative condenser units under three different air-flow rates. The results show that the air volume has a significant impact on the COP of the unit. Chen *et al.* [11] designed a new variable air volume capacity controller for air conditioning refrigeration system to adjust compressor speed and cooling capacity. The test results show that the capacity controller can accurately and continuously adjust the refrigeration capacity of the system refrigeration device. Can *et al.* [12] studied the working characteristics of active freezing beam terminal unit under variable air volume, which is helpful to the design, working principle and control strategy of active freezing beam system for improving indoor thermal environment.

For the poor refrigeration performance of the refrigeration system under low temperature conditions, the test bench is built and used for the refrigeration system, furthermore, a study is carried out on the impact of different air volumes on the cooling capacity of the refrigeration system under the conditions of 32 °C outside the warehouse and –10 °C inside the warehouse.

Design of test bench

The diagram of refrigeration system is shown as fig. 1. The main components of the system for testing include the compressor, electronic expansion valve, parallel flow heat exchanger of micro-channels inside and outside the warehouse, gas-liquid separator, oil separator, intermediate heat exchanger, liquid reservoir, drying filter, *etc.* During the refrigeration of the refrigeration system, the refrigerant becomes a high temperature and high pressure gaseous refrigerant in the compressor and then passes through the oil separator, from which the refrigerant is divided into two heat exchangers outside the warehouse. The refrigerant indirectly exchanges heat with the air outside the warehouse through the heat exchanger to become a low temperature and high pressure liquid refrigerant, then mixes at the outlet of the parallel flow heat exchanger of the two micro-channels outside the warehouse, flows through the liquid reservoir and drying filter, and after throttling and depressurizing, it becomes a liquid refrigerant with low temperature and low pressure and then enters the compressor for the next refrigeration cycle.

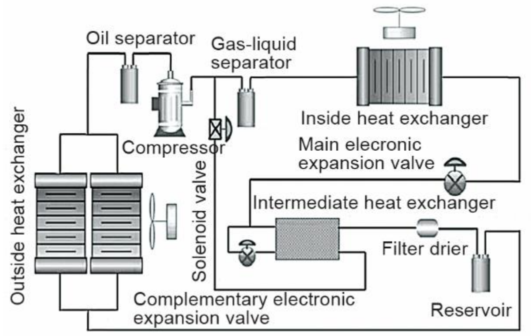

Figure 1. Refrigeration system diagram

Experimental process

A test bench is built for the refrigeration system in the laboratory, and the refrigeration coefficient and compressor power of the system are recorded, analyzed and summarized through the operation of the system under the conditions of different air volumes.

Experimental equipment

As the core component of the micro-channel parallel flow heat exchanger inside and outside the warehouse, the fan can strengthen the air circulation, which is conducive to enhancing the heat exchange capacity of the heat exchanger, and the energy consumption of the fan plays a decisive role in the energy-saving effect of the whole refrigeration system. Six Ebm K3G097 variable-frequency centrifugal fans are installed on the heat exchanger inside the warehouse, of which each fan has the maximum rated air volume of 1200 m^3/h. Five Ebm variable-frequency axial flow fans are installed on the heat exchanger outside the warehouse, of which each fan has the maximum rated air volume of 2200 m^3/h. The air volume of fans on the heat exchangers inside and outside the warehouse can be adjusted through the panel. Table 1 shows the parameters of the main equipment in the experiment.

Experimental process

The laboratory should have a simulated temperature according to the actual conditions of the refrigeration storage. To explore the cooling capacity of the refrigeration system under different low temperature conditions, the experimental scheme is formulated as tab. 2 according to GB_T30134-2013 Code for Management of Refrigeration Storage, Code for Design of Refrigeration Storage 2010, QBT4681-2014 Micro-channel Heat Exchanger for Room Air Conditioner, JBT 11967-2014 Micro-channel Heat Exchanger for Condenser of Refrigeration and Air Conditioning Equipment, GB_T25129-2010 Air Cooler for Refrigeration and other specifications and requirements.

Analysis of results

Analysis of condensing air volume results

As shown in fig. 2, when the condensing air volume is set to 45% of the unit air volume, the cooling capacity is 8.42 kW. When the condensing air volume is set to 55% of the unit air volume, the cooling capacity is 8.60 kW. When the condensing air volume is set to 65% of the unit air volume, the cooling capacity is 8.62 kW, and when the condensing air volume is set to 75% of the unit air volume, the cooling capacity is 8.56 kW. The cooling capacity first increased significantly and then decreased slightly.

Table 1. Specifications and parameters of the main components and measuring devices

Equipment	Main specifications and parameters
Compressor	Refrigerant: R404A, 540 mm/285 mm/315 mm
Heat exchanger inside the warehouse	Parallel flow heat exchanger of micro-channels, 1200 mm/586 mm/36 mm, number of flat tube rows: 54 (18:36)
Heat exchanger outside the warehouse	Two parallel flow heat exchanger 1350 mm/564 mm/36 mm, number of flat tube rows: 52 (18:34)
Fan inside the warehouse	Six Ebm K3G097 variable-frequency centrifugal fans with the max. rated air volume of 1200 m^3/h
Fan outside the warehouse	Five Ebm variable-frequency axial flow fans with the max. rated air volume of 2200 m^3/h
Electronic expansion valve of main circuit	Carel electronic expansion valve E2 V-24, with the rated cooling capacity: 21.7 kW, the adjustable range: 10~100%
Electronic expansion valve of compensating circuit	Carel electronic expansion valve E2 V-14, with the rated cooling capacity: 7.7 kW, the adjustable range: 10~100%
Intermediate heat exchanger	Jiangsu Weyee B3-014-10D-3.0, with the design capacity: 5 kW
Drying filter	Emerson drying filter EK083083S, with the capacity: 2 L
Gas-liquid separator	Customized gas-liquid separator, with the design capacity: 2 L
Liquid reservoir	Colin homemade reservoir, with the capacity: 2 L
Oil separator	Emerson oil separator, with the model: A-WC41999

Table 2. Experimental conditions

Test conditions	Comp-ressor revolving speed [rpm]	Temperature inside the storage [℃]	Temperature outside the storage [℃]	Condensing air volume [%]	Evaporating air volume [%]	Superheat of main valve [K]	Superheat of compensating valve [K]	Air compensation mode
Condition I	4000	–10	25	45~75	100	5	30	Low compensation
Condition II	4000	–10	25	65	55~100	5	30	Low compensation

As shown in fig. 3, when the condensing air volume is set to 45% of the unit air volume, the compressor power is 1.92. When the condensing air volume is set to 55% of the unit air volume, the compressor power is 1.91. When the condensing air volume is set to 65% of the unit air volume, the compressor power is 1.88, and when the condensing air volume is set to 75% of the unit air volume, the compressor power is 1.87. The compressor power is basically unchanged first and then reduced by a small margin. The system adopts low-pressure air compensation technology, so the compressor power is less affected.

Figure 4 shows that when the condensing air volume is set to 45% of the unit air volume, the COP is 4.4, while the values become 4.51, 4.55, and 4.52, respectively, when the condensing air volumes are 55, 65, and 75%. The COP first increases greatly and then decreases slightly. The change range of compressor power is small, so the change trend of COP is similar to the cooling capacity.

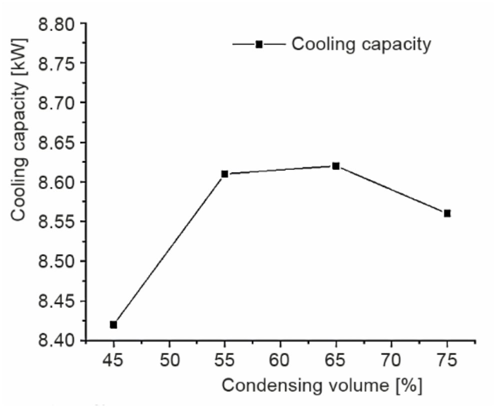

Figure 2. The effect of condensing air volume on cooling capacity

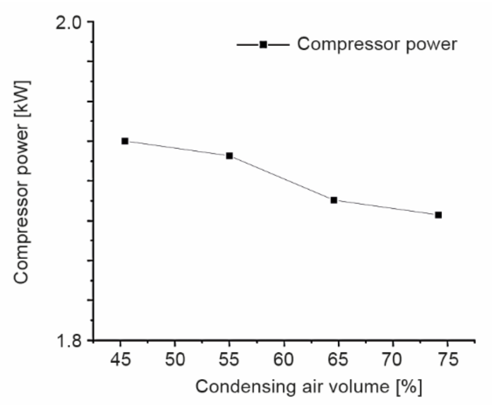

Figure 3. The effect of condensing air volume on compressor power

Figure 5 shows the effect of condensing air volume on EER. When the condensing air volume is set to 45% of the unit air volume, EER is 1.91. When the condensing air volume is set to 55% of the unit air volume, EER is 1.78. When the condensing air volume is set to 65% of the unit air volume, EER is 1.64. When the condensing air volume is set to 75% of the unit air volume, EER is 1.48. The EER decreases continuously and slightly with increasing condensing air volume.

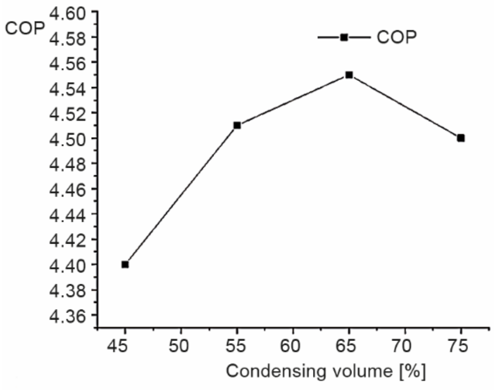

Figure 4. The effect of condensing air volume on COP

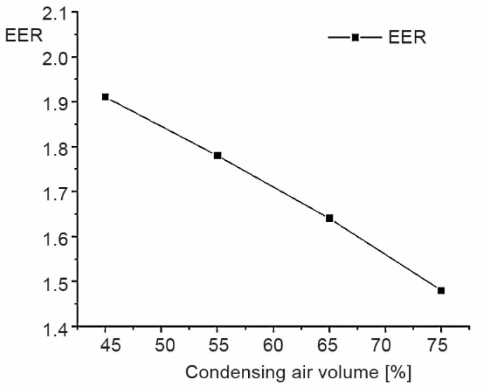

Figure 5. The effect of condensing air volume on EER

Analysis of evaporating air volume results

As shown in fig. 6, when the evaporating air volume is set to 55% of the unit air volume, the cooling capacity is 7.56 kW. When the evaporating air volume is set to 70% of the unit air volume, the cooling capacity is 8.27 kW. When the evaporating air volume is set to 85% of the unit air volume, the cooling capacity is 8.49 kW, and when the evaporating air volume is set to 100% of the unit air volume, the cooling capacity is 8.6 kW. The cooling capacity increases with increasing evaporating air volume.

As shown in fig. 7, when the evaporating air volume is set to 55% to 85% of the unit air volume, the compressor power remains stable at 1.89. When the evaporating air volume is set to 100% of the unit air volume, the compressor power is 1.9. With the increase in evaporating air volume, under working conditions similar to the previous group, the low-pressure air compensation technology basically keeps the compressor power stable.

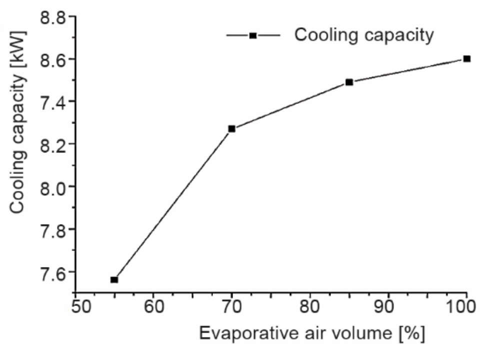

Figure 6. The effect of evaporating air volume on cooling capacity

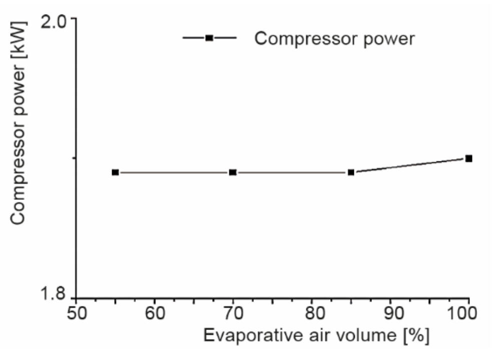

Figure 7. The effect of evaporating air volume on compressor power

Figure 8 shows that the COP values are 4.02, 4.48, 4.52, and 4.50, respectively, when the evaporating air volumes are 55, 75, 85, and 100%. The COP tends to increases with the increase of evaporation air volume. Figure 9 shows that the EER values are 1.82, 1.89, 1.75, and 1.66, respectively, when the evaporating air volumes are 55, 75, 85, and 100%. The EER tends to decrease with the increase of evaporation air volume.

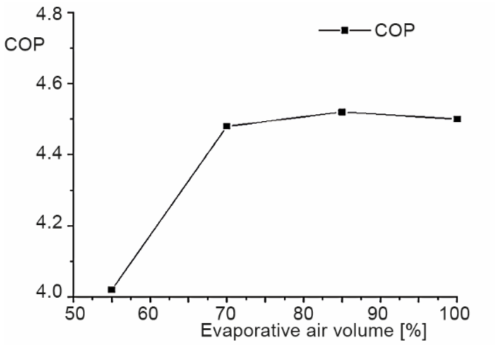

Figure 8. The effect of evaporative air volume on COP

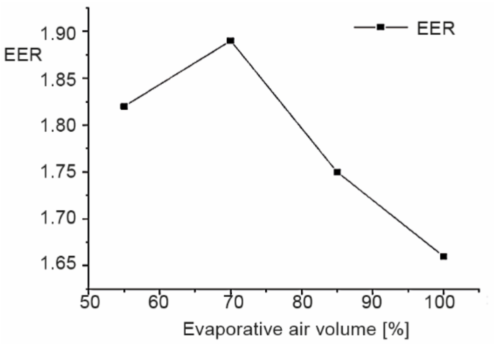

Figure 9. The effect of evaporative air volume on EER

Conclusion

According to the comprehensive analysis, when the temperature inside the warehouse is negative 10 ℃, the condensing air volume is set to 65%, the evaporating air volume is increased and set to 100%, the cooling capacity and COP can be improved effectively, and the lower EER can play a good energy-saving effect. Moreover, due to the low-pressure air compensation technology, the exhaust temperature and compressor power are basically maintained at a stable level, so that the system can not only ensure the optimal cooling capacity

[13] but also save considerable energy consumption. Therefore, the optimal cooling capacity can be guaranteed under this working condition. The future research frontier focuses on nanorefrigerants [14], nanoparticles can greatly affect the thermal properties through the boundary layer [15, 16].

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