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Research on performance optimization of tandem double evaporation temperature air conditioning unit

Bai Junwu
(University of Shanghai for Science and Technology，Shanghai 200093，China)

Abstract

The physical model has the characteristics of double cylinders, double inspirations, and double evaporators. The mathematical model is established to study the two cases of changing the number of tubes in evaporator with the cylinder volume ratio unchanged and changing the number of tubes in evaporator and the cylinder volume ratio at the same time. The results show that the unit with cylinder volume ratio of 1 and evaporator tube row ratio of 1 has the best performance. When the cylinder volume ratio and the evaporator tube row ratio are changed at the same time, the unit with the cylinder volume ratio of 0.8 and the tube row ratio of 1 has the best performance. When the cylinder volume ratio and the number of rows ratio are both 1, the simulation results obtained under the two control conditions of constant temperature and constant relative humidity are compared with the experimental data to verify the correctness of the model.

Keywords: *double evaporation temperature; Performance optimization; double evaporation*

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I. INTRODUCTION

Fresh air conditioning unit is the main equipment in air conditioning unit to deal with fresh air. The efficiency of traditional single evaporator air conditioning unit is often low because of the influence of evaporation temperature. Using double evaporator to process air twice can avoid the influence of evaporation temperature on traditional single evaporator to improve unit performance [1] and can also realize independent control of temperature and humidity [2,3]. In humid areas, the air humidity is relatively high. Independent control of temperature and humidity can improve the dehumidification capacity of the unit, reduce the indoor moisture content, and ensure the indoor air quality [4].

A lot of experiments are needed to study the refrigeration efficiency of double evaporation temperature fresh air conditioning unit and to optimize the unit, and the time and labor cost are very high. The establishment of mathematical model for simulation calculation can replace most experiments and speed up the development, design, and improvement of unit [5]. Shao et al. used simulation calculation to provide theoretical basis for their double evaporator system and reduce the research cost [6]. In the background of advocating low-carbon economy, the optimization of refrigeration system cannot be ignored, improve refrigeration efficiency, and save energy; Wang, Han et al. improved the system efficiency of their refrigeration system by optimizing it [7,8].

Zhang et al. [9] mentioned a new type of double-suction compressor with double evaporation temperatures, which can realize two refrigeration cycles with different evaporation temperatures. Weng et al. used double evaporator to set two different evaporation temperatures for the double suction compressor and divided the air treatment process into two sections, so that a refrigeration unit could use two refrigeration cycles to process air separately, which could significantly improve the unit efficiency [10].

At present, the research on double evaporation temperature unit of double cylinder double suction compressor is not mature. In this paper, based on the research of Weng [10] et al., the cylinder volume ratio and evaporator tube row ratio of double evaporation temperature air conditioning unit are studied accordingly. The steady-state mathematical model of double evaporation temperature air conditioning unit is established to provide basis for the design of evaporator tube row and volume ratio of compressor cylinder.

II. MATHEMATICAL MODEL OF DOUBLE EVAPORATION TEMPERATURE FRESH AIR CONDITIONING UNIT

Weng et al. [10] have described in detail the refrigeration cycle principle of tandem double evaporation temperature fresh air conditioning unit. Its schematic diagram is shown in Figure 1. The basic principle is as follows: The refrigerant gas with high and low evaporating pressures exits the evaporator and enters the high and low pressure cylinder of the double suction compressor for compression, and then cools into refrigerant liquid through the condenser, which is then divided into two routes. One route passes through the low-pressure expansion valve EEV2 and enters the low-pressure evaporator CC2 for evaporation. The other goes through the high-pressure expansion valve EEV1 into the high-pressure evaporator CC1 for evaporation. After evaporation, the refrigerant gas completes the cycle from the suction port of their respective compressors. External air is first cooled by heat exchange with CC1, and then heat exchange and dehumidification with CC2 after cooling by CC1, and finally sent into the room by fan.

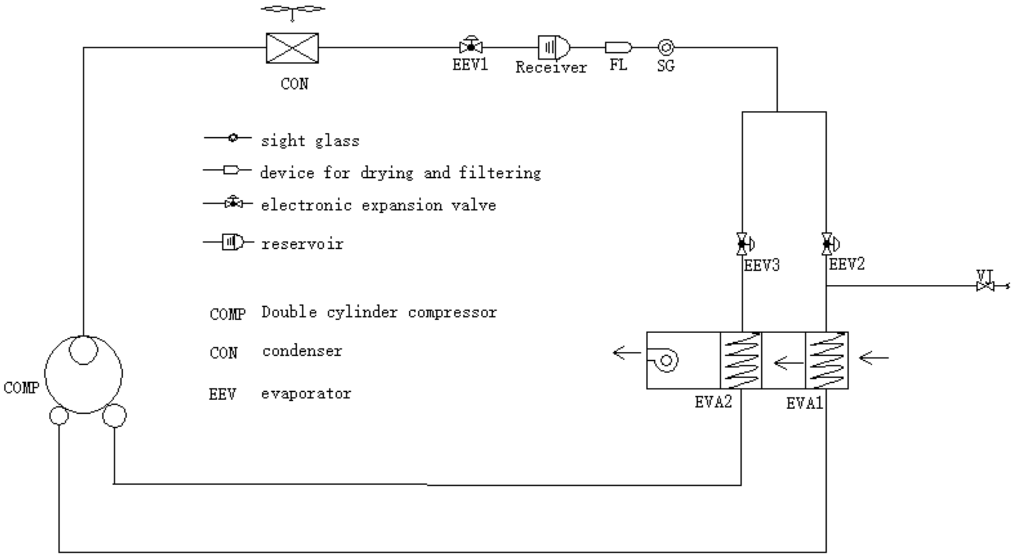

Figure 1: Schematic diagram of double evaporation air conditioning unit

In this study, a physics-based steady-state mathematical model is proposed to help fully study the performance of a tandem double evaporation temperature air conditioning unit under different cylinder volumes and heat exchanger tube row ratios. Based on the existing physical model of double evaporator air conditioning unit, the steady-state mathematical model of tandem double evaporation temperature air conditioning unit is established in this part, and its calculation process is shown in Figure 2.

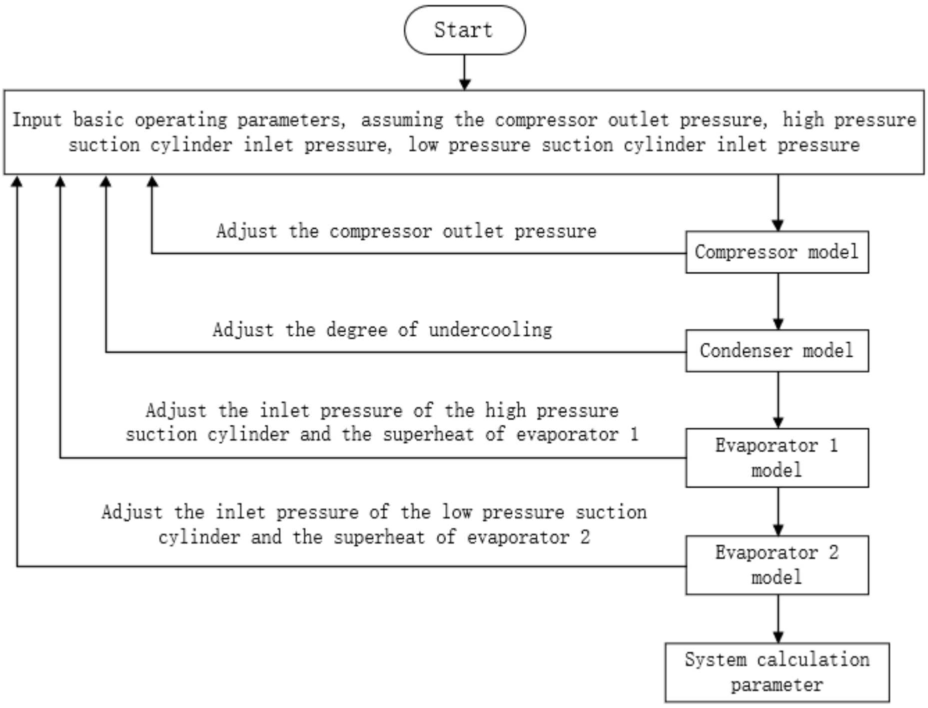

Figure 2: Model flow chart of double evaporation air conditioning unit

The flow chart is a steady-state mathematical model based on the undercooling zone, two-phase zone and overheat zone. There are three calculation modules: compressor, condenser and evaporator. Each calculation module can verify its accuracy independently to ensure the correctness of the calculation process. In addition, the throttling process of refrigerant through the expansion valve is assumed to be an isentropic process.

III. PERFORMANCE OPTIMIZATION OF DOUBLE EVAPORATION TEMPERATURE AIR CONDITIONING UNIT

3.1 Optimization analysis of tube row number performance in evaporator

Output total cooling capacity (TCC) and equipment energy efficiency ratio (COP) are often used to represent the operating characteristics of an air conditioning unit because they can reflect the overall cooling and energy conversion efficiency capabilities. Therefore, there are two important parameters in this study, i.e.

$$TCC = ma_1(ha_{51} - ha_{61}) + ma_2(ha_{52} - ha_{62}) \tag{1}$$

$$COP = TCC/(N_1 + N_2) \tag{2}$$

Where, Ma1 is the air mass flow through the high-temperature evaporator, Ha51 is the air enthalpy at the inlet of the high-temperature evaporator, and Ha61 is the air enthalpy at the outlet of the high-temperature evaporator.Ma2 is the mass flow of air passing through the low-temperature evaporator, Ha52 is the enthalpy of air at the inlet of the low-temperature evaporator, and Ha62 is the enthalpy of air at the outlet of the low-temperature evaporator.N1 is the work done by the high-pressure cylinder of the compressor, and N2 is the work done by the low-pressure cylinder of the compressor.

There are two evaporators in the double evaporation temperature air conditioning unit, and each evaporator has different cooling/dehumidification capacity. Therefore, the relative size of the two evaporators is very large in terms of their surface area. The variation of the number of tube rows will affect the overall operation characteristics of the unit. Using the established model, the effect of different tube row ratio on the operating characteristics of the unit is numerically studied. The number of main pipe rows of the two evaporators is 8, and each row has 12 tubes. The following formula is used to define the tube row ratio of two evaporators in the unit.

$$R_e = X_{e1}/X_{e2} \tag{2}$$

Xe1 is the number of tube rows of high-temperature evaporator CC1, Xe2 is the number of tube rows of low-temperature evaporator CC2.Select different Re values in the following table to study unit performance. The inlet air condition of the unit is selected as the standard working condition of the compressor, that is, the dry bulb temperature is 34.6℃ and the relative humidity is 62%, and the established model is used for calculation and research.

Table 1: Evaporator tube row numerical table

X_{e1}	2	3	4	5	6
X_{e2}	6	5	4	3	2
Re	0.3	0.6	1.0	1.3	3.0

Figure 3 and Figure 4 show the simulated operation characteristics of TCC and COP of double evaporation temperature air conditioning unit under standard operating conditions. When Re value was 1.0, TCC and COP peaked at 6.012Kw and 4.014, respectively. In the process of Re value from 0.3 to 3.0, the cooling capacity of CC1 increases rapidly at first, and then tends to be stable and begins to decline, while the cooling capacity of CC2 decreases slowly as a whole, resulting in the maximum cooling capacity of 6.012kW when Re value is 1.0.

In the process of Re value from 0.3 to 3.0, the power of CC1 is less affected by the surface area of tube discharge when dealing with the same air condition. With the increasing surface area of tube discharge of CC1, the power of CC1 increases slowly first and then decreases slowly. However, CC2 is greatly affected by the tube discharge surface area when it deals with the air in the same state. As the tube discharge surface area of CC2 decreases continuously, the power of CC2 decreases rapidly and then flattens out. Unit power shows a slow decline. As TCC reaches a maximum of 6.012Kw when Re value is 1.0, COP of the unit also reaches a maximum of 4.014 when Re value is 1.0.

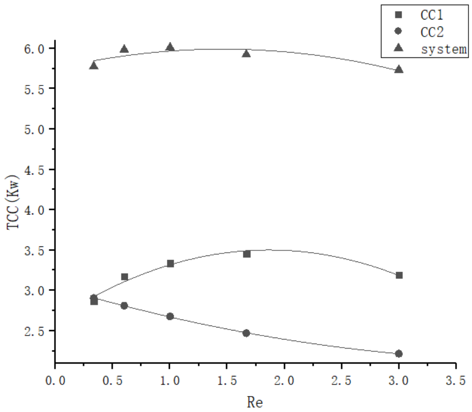

Figure 3: TCC at different Re values

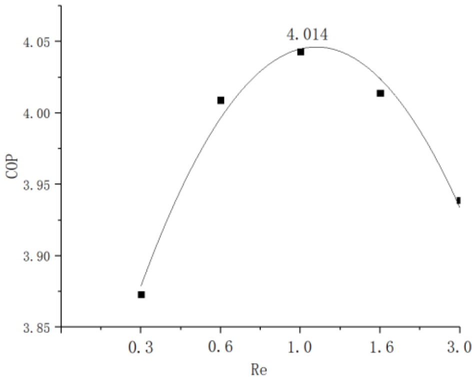

Figure 4: COP at different Re values

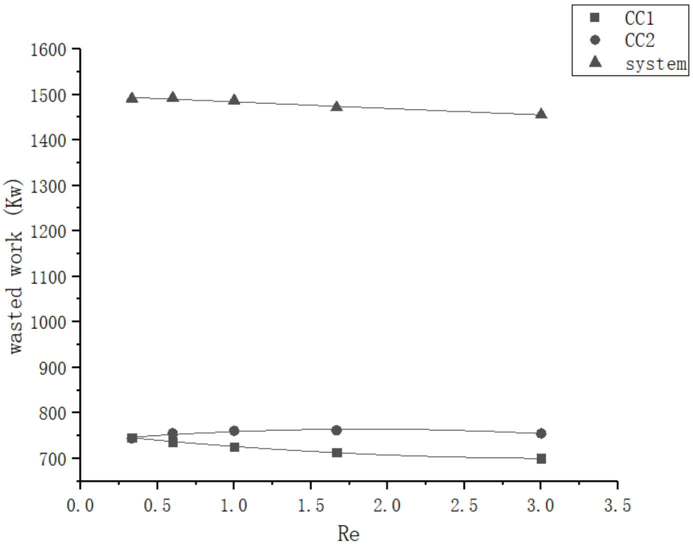

Figure 5: Power at different Re values

The simulation results show that the cooling capacity TCC and energy-efficiency ratio COP reach peak values when the number of tube rows of high and low temperature evaporator is 1:1. Therefore, the optimal ratio of high and low temperature evaporator tube row of the unit should be 1:1 to achieve the best operation characteristics.

3.2 Bivariate optimization analysis of cylinder volume and tube row

The double evaporation temperature air conditioning unit studied in this paper has not only two evaporators, but also two cylinders for its compressor [9]. The refrigerant states compressed by high and low pressure cylinders are different, and their volume changes will affect the overall operation characteristics of the unit. Weng et al. [10] have made a corresponding study on the influence of only changing cylinder volume on unit performance, and the unit performance is the highest when the cylinder volume ratio is 0.8 ~ 1.3.When the number of evaporator tube row and the volume of compressor cylinder change at the same time, the change of unit performance is studied as follows.

In this study, the total volume of high and low pressure cylinders of the compressor is 20ml.The following formula is used to define the volume ratio of two compressor suction cylinders in the unit

$$R_c = V_{C1}/V_{C2} \qquad （4）$$

Where VC1 is the volume of high-pressure cylinder, VC2 is the volume of low-pressure cylinder. Select different Rc values in the table below to study unit performance. The inlet air condition also selects the standard working condition of the compressor. The simulation results are shown in FIG. 6 and FIG. 7.

Table 2 compressor cylinder volume table

V_{C1}	7	8	9	10	11	12	13
V_{C2}	13	12	11	10	9	8	7
Rc	0.54	0.66	0.82	1.0	1.2	1.5	1.86

FIG. 6 and 7 show the TCC and COP change curves of fresh air conditioning units when Re and Rc change simultaneously. It can be seen from FIG. 6 that when Re value is 1.0, TCC increases first and then decreases with the increase of Rc value, and reaches its maximum when Rc=0.9. When Re < 1.0, TCC presents a continuous upward trend, and better unit performance can be achieved by increasing Re. When Re > 1.0, TCC showed a trend of continuous decline, indicating that when Re > 1.0 and Re continued to increase, unit performance decreased.

FIG. 7 shows that when Re value is 1.0, COP increases first and then decreases with the increase of Rc value and reaches the maximum when Rc=0.9. When Re < 1.0, COP shows an upward trend and begins to decline when Rc=1.5, indicating that good unit performance can be achieved under this condition, but COP at this time is smaller than COP under Re=1.0 and Rc=0.9. When Re > 1.0, TCC showed a downward trend, indicating that when Re > 1.0 and Re continued to increase, unit performance continued to decline. Therefore, the best structure design of air conditioning units should be designed according to the volume ratio of 0.9, the number of pipe row ratio of 1.0.

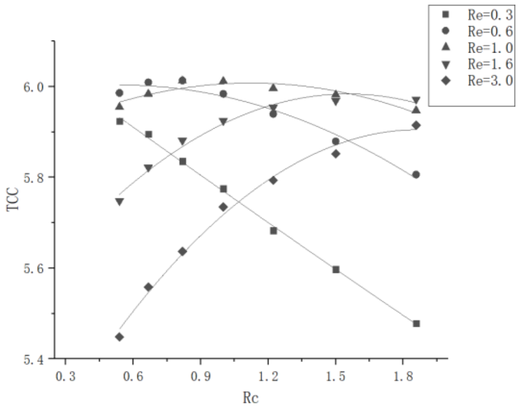

Figure 6: Change curve of bivariate TCC

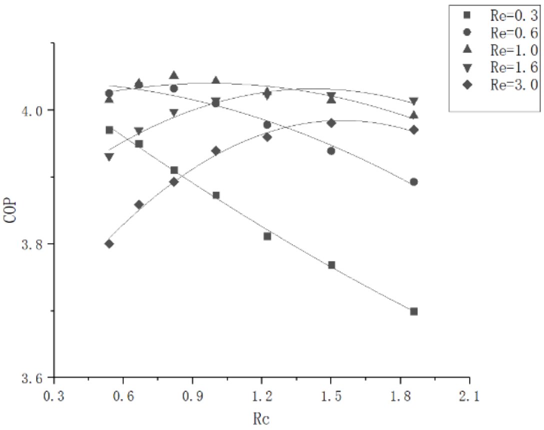

Figure 7: Change curve of bivariate COP

The simulation results show that TCC and COP of air conditioning unit reach maximum values when Rc value is 0.9 and Re value is 1.0. Therefore, the optimal high and low cylinder volume ratio of the air conditioning unit should be 0.9, and the number of tube rows of high and low pressure evaporator should be allocated according to 1.0 to achieve the best operation characteristics.

IV. EXPERIMENTAL VERIFICATION OF DOUBLE EVAPORATION TEMPERATURE AIR CONDITIONING UNIT MODEL

In order to verify the mathematical model of double evaporation temperature air conditioning unit used in this study, a prototype experimental unit was designed in accordance with the principle shown in Figure 1.The enthalpy difference laboratory is used to create the necessary indoor and outdoor air conditions, which are handled separately by the existing air-conditioning load generator. In the present study, fixed speed of compressor, fan and condenser fan are used.The schematic diagram of the prototype experimental unit is shown in Figure 8. The main components of the prototype experimental unit include compressor COMP, two sets of evaporators CC1 and CC2, condenser CON and electronic expansion valves EEV1 and EEV2.

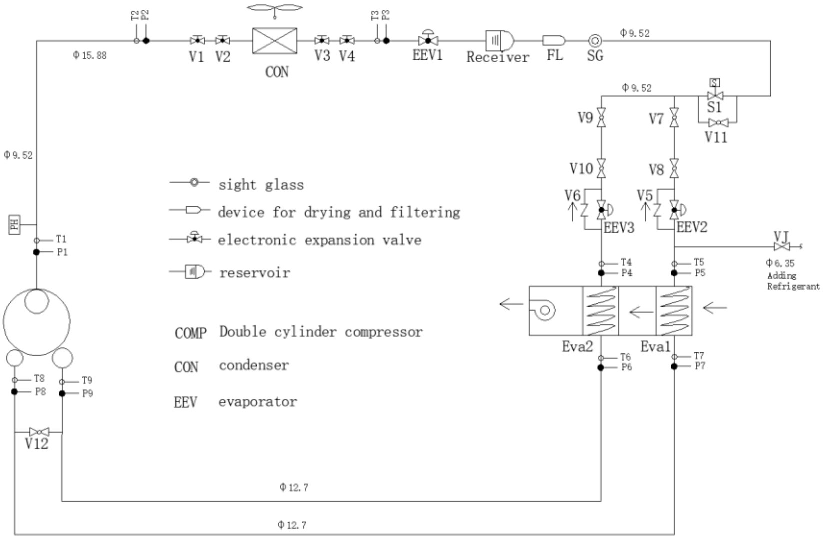

Figure 8: Schematic diagram of air conditioning unit experiment

4.1 Model experimental verification

The compressor, fan speed and air mass flow rate of the proposed double evaporation temperature air conditioning unit are fixed when it runs. Therefore, the refrigerant mass flow through CC1 and CC2 is the factor affecting the output TCC and COP of air conditioning units. By adjusting the opening degree of EEV1 and EEV2, the mass flow rate of refrigerant can be changed and the superheat of high and low pressure evaporator can be affected accordingly. Considering that different inlet states may also affect unit TCC and COP, the inlet air state is maintained within a constant range by adjusting the enthalpy difference laboratory.

The verification process of the model test is as follows: the indoor air is controlled to achieve the required experimental air intake state. By constantly adjusting the opening of EEV1 and EEV2, the superheat of the high and low pressure evaporator reaches 7℃ and is in a stable operation state. On this basis, the key parameters of the experimental air conditioning unit were recorded continuously for 15min at 1min interval, and the average value of the measured data was calculated, and the TCC and COP of the experiment were obtained by calculation. By using the model, the predicted TCC and COP were obtained and compared with the experimental values.

The same experimental conditions and Settings were taken in the experiment and simulation. The dry bulb temperature and relative humidity were unchanged for the inlet air parameters for experimental verification. The inlet air parameters are shown in the following table:

Table 3: Air state parameter table

Keep the inlet air dry bulb temperature (35.5℃) unchanged	relative humidity				
	50	55	60	65	70
Keep inlet air relative humidity (75%) unchanged	dry-bulb temperature				
	26	28	30	32	34

The prediction and experimental results of TCC and COP that kept the inlet air dry bulb temperature unchanged are shown in Figure 9 and 10. The difference between TCC prediction and experimental results decreases with the increase of relative humidity, and the difference is the largest when the relative humidity is 50%, with a deviation of 1.79%. The difference between COP prediction and experimental results increases with the increase of relative humidity, but the deviation tends to be stable and the maximum deviation is 1.8% when relative humidity is 70%.

It was observed that the rerun column bottom stream temperature has greater effect on the linear alkylbenzene yield than the temperature variation of the top stream. At higher temperature of both streams , lower percentage yield of average wt. % of linear alkylbenzene was obtained with that of the top stream being the lowest at 87.5% as against 93.3% for the bottom stream. The highest linear alkylbenzene yield of 99.4%was recorded at bottom stream temperature of 280oC and pressure of 115Kpa.

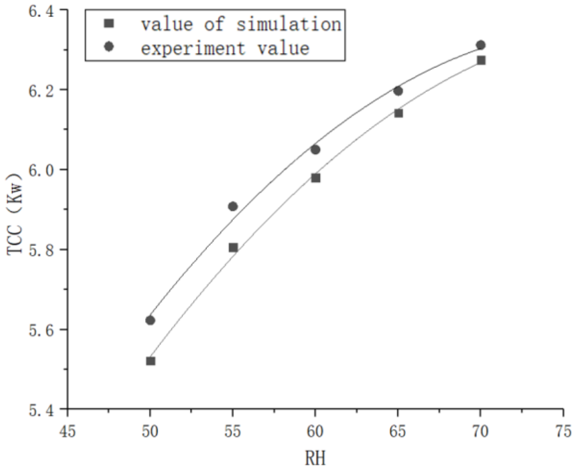

Figure 9: TCC error comparison of fixed dry-bulb temperature

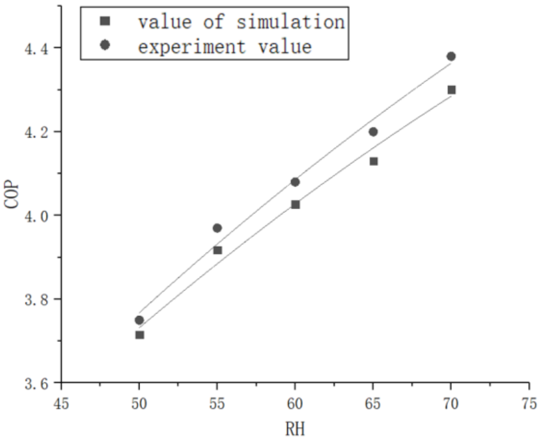

Figure 10: COP error comparison of fixed dry bulb temperature

The prediction and experimental results of TCC and COP, which kept the inlet air relative humidity unchanged, are shown in the figure below. The difference between TCC prediction and experimental results increases with the increase of dry bulb temperature, but the deviation tends to be stable, and the biggest difference is 3.79% when the dry bulb temperature is 34℃. There was little difference between COP prediction and experimental results, and the maximum deviation was 1.01% when the dry bulb temperature was 26℃.

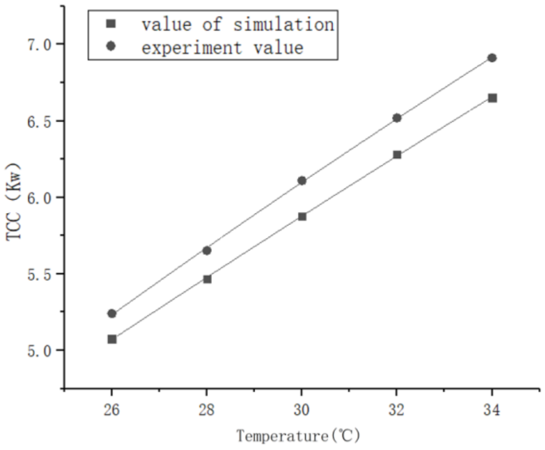

Figure 11: Comparison of TCC error for fixed relative humidity

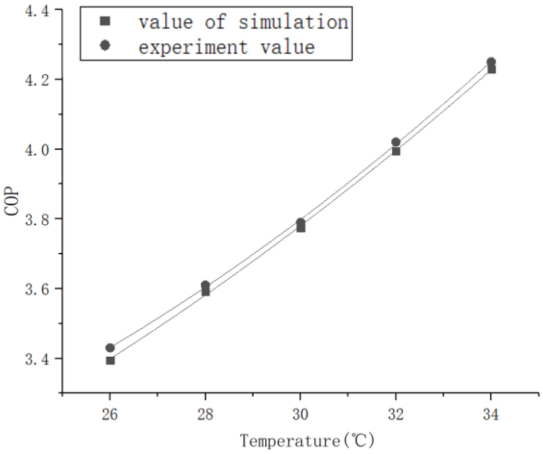

Figure 12: Comparison of COP error for fixed relative humidity

The above comparison results show that the established model can well predict the operation characteristics of TCC and COP of double evaporation temperature air conditioning unit under different inlet conditions. Therefore, it has been used in modeling studies to demonstrate that dual evaporative temperature air conditioning units can provide high-precision TCC and COP prediction results.

V. CONCLUSION

i. In this study, the experimental verification of the tandem double evaporation temperature air conditioning unit was carried out by setting up an experimental platform, which proves that the model has good prediction accuracy.

ii. The results show that the cooling capacity TCC and energy-efficiency ratio COP of fresh air air conditioning unit are optimal when the ratio of cylinder volume of compressor is kept unchanged and the number of tube rows of two evaporators is 1:1. When the ratio of tube rows changes, the cooling capacity TCC and energy-efficiency ratio COP will decrease correspondingly.

iii. The results show that when the ratio of compressor cylinder volume and the ratio of high and low evaporator tube row are changed simultaneously, the cooling capacity TCC and energy efficiency COP of fresh air conditioning unit are optimal when the ratio of compressor cylinder volume is 0.9:1 and the tube row of two evaporators is 1:1.

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