RESEARCH OF THE AIR SOURCE HEAT PUMP AND THE WATER SYSTEM

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Abstract： By adjusting the operation parameters of an air source heat pump system e.g. decreasing the supply water temperature in cooling operation mode or increasing the supply water temperature in heating operation mode, the air conditioning system can be running more economically while the efficiency decreases. In this paper, we tested the relations among the operation parameters of the system, water system parameters and the overall cost during the life cycle of the heat pump system, we also made the evaluation on energy efficiency and technology of an actual project cases and proposes an optimization option.
Keywords: air source heat pump, low temperature, air conditioning, water system, energy efficiency analysis

Introduction

The system consisting of air source heat pump and its water system is widely used in room air-conditioning of small house.

In such a system, the economic character of unit operation is in contradiction with the economic character of air-conditioning system. The economic character of air-conditioning system can be improved by adjusting the operation parameters of air source heat pump unit such as reducing the cold water temperature in refrigerating mode, or increasing the hot water temperature in heat pumping mode. But in the mean time, the economic character of heat pump unit is decreased. Therefore, it is very useful to study the relationship of operating conditions, control mode and total energy efficiency of an air source heat pump system.

Aiming at the optimal energy efficiency of such a unit in heat-pumping mode, Jiang Yiqiang [1] studied the relationship between heat pump unit and its assistant heat source under a certain operating condition, the optimal balance point of energy utilization of an air source heat pump system was put forward. With temperature frequency method, Mr. Li Junhua present the switching condition between heat pumping and assistant electrical heating [2].

B. Kilkis compared the operating efficiencies of an air source heat pump system under different condensing condition [3]. With the thermodynamic analysis, Si-moon Kim discussed the relationship between thermodynamic operating parameters and energy efficiency of system, and the principle to determine this relationship [4]. Mrs. Yang Zhao made great efforts to apply the principle of exergy and the non-equivalence principle [5] of exergy to the economic analysis of air-conditioner operation.

Taking the operating energy efficiency as optimal objective, the author of this paper studied the making up relationship between heat exchangers of an air source heat pump, and the relationship between the air conditions of out door unit and the operating parameters of the heat pump [6]. Thus, the making up relationship of heat exchangers was determined.

In this paper, the author studied the influences of operating parameters of unit and the water parameters on the energy efficiency of system. The optimal operating parameters were put forward.

1. MODEL AND ANALYSIS

Under a constant out-door operating condition of heat pump and in refrigerating mode, the change of operating efficiency when adjusting the in-door operating parameters is the change of operating efficiency due to the change of evaporating condition under a constant condensing condition.

1.1 REFRIGERANT PARAMETERS AND UNIT ENERGY CONSUMPTION

The main performance parameters such as refrigeration capacity, input power and operating efficiency will be determined with the determination of working conditions (Te, Tc, Tsh, Tsc). i.e.

Refrigeration capacity: Q0=Q0 (Te, Tc, Tsh, Tsc)

Input power: Pj, i=Pj,i(Te, Tc, Tsh, Tsc)

Efficiency: COP=Q0/Pj,i=COP(Te, Tc, Tsh, Tsc)

For a certain air-conditioner unit and under constant condensing condition, the above parameters are only dependent on evaporating condition. i.e.

Refrigeration capacity: Q0=Q0 (Te, Tc, Tsh, Tsc)=Q0 (Te)

Input power: Pj,i=Pj,i(Te, Tc, Tsh, Tsc)=Pj,i(Te)

In a whole cycle of refrigeration, the total refrigeration capacity of this unit is:

$$Q_j = \int Q_0(T_e) \cdot d\tau \quad (1)$$

The energy consumption of this unit is:

$$E_j = \int P_{j,i}(T_e) \cdot d\tau \quad (2)$$

1.2 PARAMETERS AND ENERGY CONSUMPTION OF WATER PUMP

Temperature difference between input and output water

$$\Delta T_{w,io} = T_{w,i} - T_{w,o} \quad (3)$$

The heat transfer in waterside:

$$Q_w = \int m_w \cdot c_w \cdot (T_{w,i} - T_{w,o}) \cdot d\tau \quad (4)$$

The temperature difference between cold water and refrigerant:

$$\Delta T_{w,r} = \frac{\Delta T_{w,io}}{\ln \dfrac{T_{w,i} - T_e}{T_{w,o} - T_e}} \quad (5)$$

From (5), the relationship between evaporating temperature and water parameters can be obtained (6):

$$T_e = \frac{T_{w,i} - T_{w,o} \cdot e^{\frac{\Delta T_{w,io}}{\Delta T_{w,r}}}}{1 - e^{\frac{\Delta T_{w,io}}{\Delta T_{w,r}}}} \quad (6)$$

The heat transfer in refrigerant side (the total refrigerating capacity) is equal to the heat transfer in waterside. Therefore, the flow rate of cold water can be determined with (1) and (4). i.e.

$$m_w = \frac{\partial Q_w}{\partial \tau} \cdot \frac{1}{c_w \cdot \Delta T_{w,io}} \quad (7)$$

The energy consumption of water pump can be determined according to the relationship between the flow rate and the power of water pump:

$$E_{w,p} = \int P_w(m_w) \cdot d\tau \quad (8)$$

1.3 IN-DOOR AIR-SIDE PARAMETERS AND ENERGY CONSUMPTION OF FAN

The temperature difference between input and output air is:

$$\Delta T_{a,io} - T_{a,i} - T_{a,o} \quad (9)$$

If there is not any condensing water, the heat transfer in airside is:

$$Q_a = \int m_a \cdot c_a \cdot (T_{a,i} - T_{a,o}) \cdot d\tau \quad (10)$$

The airflow rate flowing through indoor unit is:

$$m_a = \frac{\partial Q_a}{\partial \tau} \cdot \frac{1}{c_a \cdot \Delta T_{a,io}} \quad (11)$$

The power of the fan is a function of airflow rate, which varies with airflow rate. i.e. Pa=Pa(ma),Thus, the heat transfer in airside can be determined:

(11)

$$Q_a \approx Q_w - P_a \approx Q_j - P_a \quad (12)$$

The energy consumption of the fan of indoor unit is:

$$E_a = \int P_a(m_a) \cdot d\tau \quad (13)$$

With a constant surrounding condition and certain adjusting load, the influences of operating parameters of unit and water on total energy consumption are expressed as the influences on Ej, Ew and Ea. That means that, in the opinion of energy saving, the Max(Ej+Ew+Ea) is the base to determine the operating parameters of unit and water.

2. CASE ANALYSIS

2.1 BASIC SPECIFICATION OF THE UNIT

A condensing unit of COPELAND ZR84KCE-TF5, used in boarding house in Beijing as an air conditioner, takes R407C as refrigerant. The total power of unit fan and control system is 465 watts.

The making up of the unit parts is determined according to the principles and methods presented in the reference [7], [8].

A plate heat exchanger is used for the heat transfer between refrigerant and water. The evaporating temperature is 5℃，the temperature difference of heat transfer between refrigerant and water, $\Delta T_{r,w}$, is 4℃.

2.2 UNIT SYSTEM

2.2.1 THE EFFECT OF EVAPORATING TEMPERATURE ON THE REFRIGERATION CAPACITY OF THE UNIT

The refrigeration capacity of the unit varies with the evaporating temperature. Fig. 1 shows their relationship.

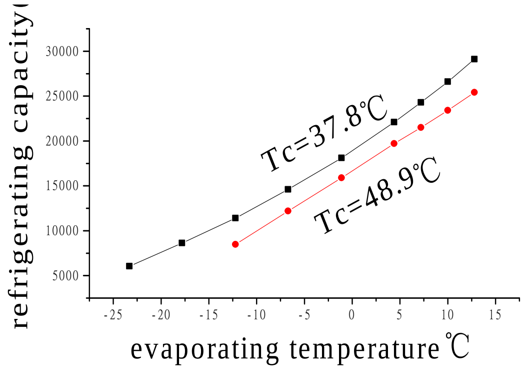

Fig. 1 The relationship between refrigerating capacity and evaporating temperature

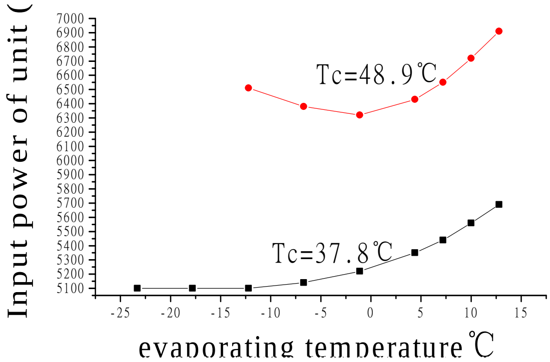

Fig. 2 The relationship between The input power of the unit and evaporating temperature

Fitting the testing data, the relationship between refrigerating capacity and evaporating temperature can be obtained:

When condensing temperature is equal to 37.8℃,

$$Q_0(T_e) = 18887.26324 + 692.52747 \cdot T_e + 7.45924 \cdot T_e^2 + 0.05941 \cdot T_e^3 \quad (14)$$

When condensing temperature is equal to 48.9℃

$$Q_0(T_e) = 16674.78778 + 669.24787 \cdot T_e + 0.2749 \cdot T_e^2 + 0.04426 \cdot T_e^3 \quad (15)$$

2.2.2 THE INFLUENCE OF EVAPORATING TEMPERATURE ON ENERGY CONSUMPTION OF UNIT

The energy consumption of the unit varies with the evaporating temperature. Fig.2 shows their relationship.

Fitting the testing data, the relationship between energy consumption of the unit and the evaporating temperature can be obtained:

When condensing temperature is equal to 37.8℃:

$$P(T_e) = 5239.36 + 20.70 \cdot T_e + 0.96 \cdot T_e^2 + 0.014 \cdot T_e^3 \quad (16)$$

When condensing temperature is equal to 48.9℃:

$$P(T_e) = 6336.3 + 13.772 \cdot T_e + 2.392 \cdot T_e^2 \quad (17)$$

The testing results show that the input power of the unit does not vary with the evaporating temperature, when the evaporating temperature is lower than -12℃.

The input power of the unit keeps a constant value when the condensing temperature is lower than 40℃ and the evaporating temperature is set lower than -12℃. The input power of the unit increases with the decrease of the evaporating pressure when the condensing temperature is higher than 40℃ and the evaporating temperature is set lower than -12℃.

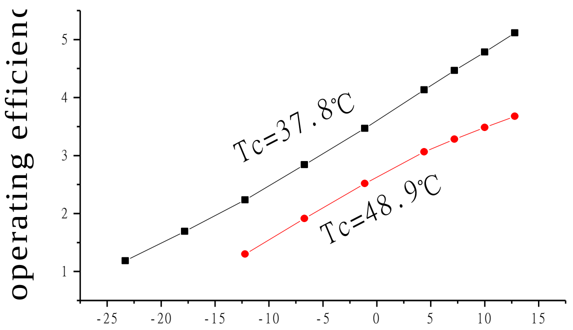

Fig. 3 The relationship between The operating efficiency of the unit and evaporating temperature

2.2.3 THE INFLUENCE OF EVAPORATING TEMPERATURE THE OPERATING EFFICIENCY OF THE UNIT

The operating efficiency of the unit varies with the evaporating temperature. The relationship between them is shown in Fig. 3.

Fitting the testing data, the relationship between operating efficiency of the unit and the evaporating temperature can be obtained:

When condensing temperature is equal to 37.8℃

$$COP(T_e) = 3.607 + 0.1174 \cdot T_e + 2.47356 \times 10^{-4} \cdot T_e^2 - 1.37795 \times 10^{-5} \cdot T_e^3 \quad (18)$$

When condensing temperature is equal to 48.9℃

$$\mathrm{COP}(\mathrm{T_e}) = 2.6302 + 0.1001 \cdot \mathrm{T_e} - 0.001 \cdot \mathrm{T_e^2} - 3.495 \cdot \mathrm{T_e^3} \quad (19)$$

2.3 WATER SYSTEM

There are two ways to control the water system. One is to adjust the flow rate of the water pump with constant water parameters; the other is to adjust the temperatures of output and input water with constant flow rate.

The author will discuss the first way later in another paper. In this paper, the second one will be discussed.

For the plate-type heat transfer presented in section 2.1, the relationship between Δ Tr,w (and the mean temperature of output and input water Tw) and the evaporating temperature can be determined according to Fig. 1, formula (14) and (15).

When condensing temperature is equal to 37.8℃:

$$\Delta T_{w,r} = 3.35676 + 0.12308 \cdot T_e + 1.33 \times 10^{-3} \cdot T_e^2 + 1.05579 \times T_e^3 \quad (20)$$

When condensing temperature is equal to 48.9℃:

$$\Delta T_{w,r} = 3.33493 + 0.13385 \cdot T_e + 5.5 \times 10^{-5} \cdot T_e^2 + 8.852 \times 10^{-5} \cdot T_e^3 \quad (21)$$

For the cold water system, with a constant input water temperature, the relationship between evaporating temperature and the temperature difference and the mean temperature of the water can be determined with formula (3), (4), (5) and Fig. 4.

$$\Delta T_{w,io} = \Delta T_{w,r} \cdot \ln \frac{T_{w,i} - T_e}{T_{w,i} - T_e - \Delta T_{w,io}} \quad (22)$$

$$T_w = \frac{T_{w,i} + T_{w,o}}{2} \quad (23)$$

Fig. 5 shows the relationship between the mean temperature of the water Tw and the evaporating temperature Te.

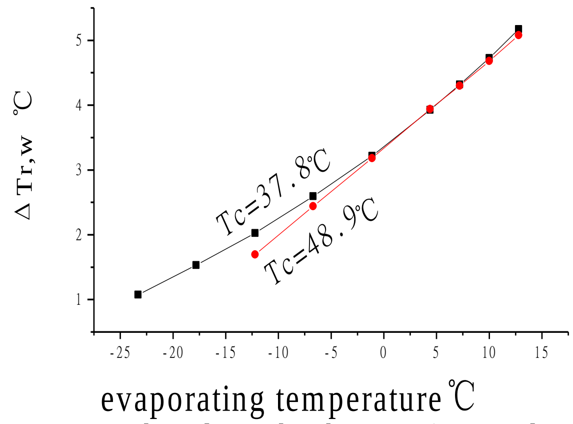

Fig.4 The relationship between Δ $T_{r,w}$ and evaporating temperature

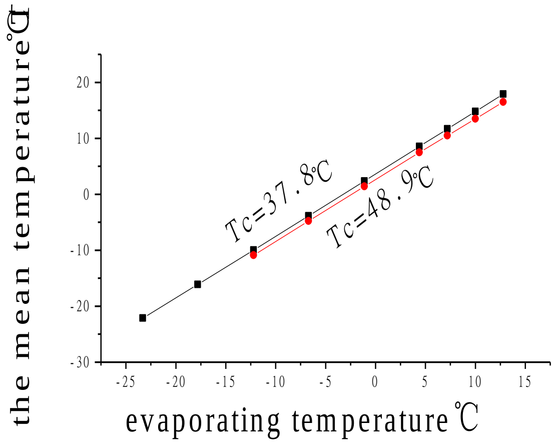

Fig.5 The relationship between Δ $T_{r,w}$ and evaporating temperature T_e.

2.4ADJUST SYTEM OF INDOOR VENTILATION

For the adjust system of indoor ventilation, the relationship between evaporating temperature Te and output temperature, cycling rate of air will be studied under a constant input temperature of air.

The temperature difference of indoor heat exchanger is:

$$\Delta T_{w,a} = \frac{T_{a,i} - T_{a,o}}{\ln \frac{T_{a,i} - T_w}{T_{a,o} - T_w}} \quad (24)$$

The derivative of formula (11) is change of airflow rate caused by the change of evaporating temperature. i.e.

$$\frac{\partial m_a}{\partial T_e} = \frac{\partial}{\partial T_e}\left(\frac{\partial Q_a}{\partial \tau} \cdot \frac{1}{c_a \cdot (T_{a,i} - T_{a,o})}\right) \quad (25)$$

When the input air temperature keeps constant (Ta,i=26℃), taking the air flow rate at 7.2℃of evaporating temperature as benchmark, to solve equation (25), the relationship between evaporating temperature and air flow rate.

The necessary input power corresponding to different airflow rates can be looked up according to the performance curve of the fan. Then, the energy consumption the fan can be obtained with the working time.

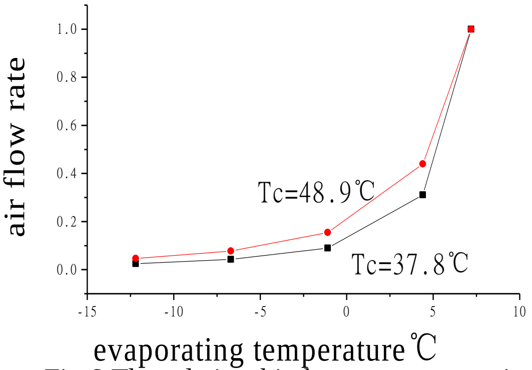

Fig.6 The relationship between evaporating temperature and air flow rate.

2.5 THE ANALYSIS OF ENERGY CONSUMPTION

It is clear from above mentioned that the input powers of the unit, the water pump and the fan are closely related to the evaporating temperature.

The input powers of the unit and the indoor fan are relatively low when the evaporating temperature is set at a low value. But, for a same adjusting load, the unit needs working for longer time due to its smaller refrigeration capacity.

For the control mode discussed in this paper, the flow rate of water system is independent on the evaporating temperature. The input of water pump does not vary with the evaporating temperature. Therefore, for a same adjusting load, the minimum sum of unit power and fan power can be found by studying the variety of this sum at different evaporating temperature.

For the air source heat pump/air conditioning system mentioned in section 2.1, the main testing parameters and the energy consumption are shown in Table 1. when the condensing temperature is 37.8℃ and 48.9℃respectively.

Table 1. The Testing results of the Energy Consumption of System

Condensing Temperature 37.8℃				
T_e(℃)	−1.1	4.4	7.2	10
Refrigerating capacity kW	18.1	22.1	24.1	26.2
Input Power of unit KW	5.22	5.35	5.44	5.56
Input Power of fan W	36	60	260	1600
Total tested power KWh/24h	14.429	12.353	11.826	13.664
Condensing Temperature 48.9℃				
T_e(℃)	−1.1	4.4	7.2	10
Refrigerating capacity kW	15.9	19.9	21.3	23.0
Input Power of unit KW	6.22	6.30	6.65	7.72
Input Power of fan kW	58	86	250	720
Total power tested KWh/24h	19.742	16.045	16.197	17.218

It is clear from these testing results that the evaporating temperature greatly influences the total energy consumption. The total energy consumption varies with the evaporating temperature; the evaporating temperature corresponding to the minimum total energy consumption varies with the change of condensing condition.

CONCLUSIONS

For the same adjusting load, the coupling relationship between unit operating parameters and the flow rate, the parameters of cold water is closely related to the total energy consumption.

The optimal parameters of the unit are certain at a certain condensing condition; it will vary with the change of condensing condition.

The influence of condensing condition on the optimal parameters of the unit is worth to be further discussed. This work will be done later.

Symbols:

T:	Temperature, ℃	Q:	Capacity, W
P:	Power, W	E:	Energy comsumption
M	Mass. Kg/s;	c:	Specific heat, w/kg.k;
τ	Time , s		

Sub-symbols:

e:	Evaporating	c:	Condensing
sh:	Over heating	sc:	Sub-cooling
w:	Water	a:	Air
i:	Input	o	Output
j:	Unit	r:	Refrigerant

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