Study on the influence factors of energy efficiency ratio of low temperature air source heat pump

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Abstract: In this paper, through the experimental study of two heating seasons, it is found that the heat pump installation position and orientation, circulating pump work/frequency conversion, frosting conditions, etc. have a greater impact on the heat pump unit energy efficiency ratio. According to the actual operation data and theoretical derivation, the analysis shows that the energy efficiency ratio increases by 2.4% when the installation position and orientation increase the air temperature by 1K. The circulating water pump can save 78% of the power consumption in the period by changing the power frequency to frequency conversion. The frosting condition diagram can make a reasonable configuration and operation prediction for the heat pump system.

1 Introduction

In recent years, with the promotion of clean energy heating by the state, low-temperature air source heat pump has been widely used as a supplementary heating equipment in severe cold area. The application places are mostly park management rooms, public buildings and office buildings which are far away from the urban heating pipe network.

At present, the various manufacturers of low temperature air source heat pump can achieve -35°C, the minimum working temperature at the time of product test efficiency is very high, however, in the practical application process, we encounter many problems that are not encountered in the laboratory, for example, the actual installation position and orientation of the equipment, the serial and parallel connection of multiple equipment, the installation spacing of multiple equipment, the matching of equipment and terminal capacity, the ratio and control logic of equipment and auxiliary heat source, the frequency conversion of circulating pump, defrosting control logic, etc, whether the circulating pump is variable frequency, and the defrost control logic, these are the main factors influencing the cop value [1,2], this article analyzes the factors such as the actual installation orientation and position of the equipment, whether the circulating water pump is equipped with variable frequency, and frosting conditions.

2 Influence of installation orientation and location

The equipment used in the experiment in this paper is installed on the first floor in the north direction of the building, and the results obtained from the actual test point in the north-south direction are compared with those obtained from the test point outside the sixth floor and the first floor in the same location. Through the actual test and statistical analysis, the equipment is installed in different orientations, south direction is 0.75°C higher than north direction, same direction (north direction) the first floor is 1.25°C higher than the sixth floor.

The model of low-temperature air source heat pump used in this experiment is MAC340, the heat production under standard working conditions is 100kW, the minimum working environment temperature is -30°C, two compressors, a single power of 30kW, the configured water pump power is 1.1kw. The nominal heating condition is the outlet water temperature of 45°C and the outdoor air dry ball temperature of 7°C, which is assumed to be the condensation temperature (T_1) and evaporation temperature (T_2). The actual condensation temperature is higher than the temperature of the tested medium and the evaporation temperature is lower than the ambient temperature.

Under this hypothesis, the nominal operating condition energy efficiency ratio of the experimental equipment is:

$$\text{cop} = T_1 / (T_1 - T_2) = (45 + 273) / [(45 + 273) - (7 + 273)] = 8.368$$

When the air inlet temperature of the outdoor

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evaporator increases or decreases, the influence on the efficiency can be calculated by the above formula, and

table 1 is obtained.

Table 1 Effect of increasing or decreasing the inlet air temperature of outdoor evaporator on the cop value

Evaporation temperature (°C)	0	1	2	3	4	5	6	7	8	9	10
Heating cop value	7.067	7.227	7.395	7.571	7.756	7.950	8.154	8.368	8.595	8.833	9.086
cop/8.368	0.844	0.864	0.884	0.905	0.927	0.950	0.974	1.000	1.027	1.056	1.086
The temperature goes up by 1K											
Cop increased relative value by %		1.919	2.009	2.104	2.207	2.317	2.436	2.564	2.703	2.853	3.016

As can be seen from table 1, under heat pump heating conditions, assuming that the condensation temperature remains unchanged, the cop value of heat efficiency also increases with the increase of evaporation temperature. On the whole, for every 1K increase, the cop increases by 2.4% on average^[3]. Therefore, the influence of installation location and orientation on heating efficiency cannot be ignored.

3 Circulating water pump power frequency/frequency conversion

In the actual test operation, the circulating water pump between the heat pump unit and the user runs at the power frequency. In addition, the circulating water pump is controlled by starting and stopping of the unit, that is, the heat pump starts the circulating water pump, and the indoor temperature basically meets the requirements after the water temperature of the heat pump unit reaches the set value during the heat pump operation. The unit stops working, but the circulating water pump still runs at a working frequency, resulting in waste. Only after the heat pump unit power off, the circulation pump will stop running. This control logic causes the contradiction between the fluctuation of building load and the unadjustable water pump, and causes the problem of "large flow rate and small temperature difference" in the transmission and distribution system under partial load, which leads to the excessive power consumption of circulating water pump. This experimental project has been tested in two heating seasons of 2017-2018 and 2018-2019, and the electricity consumption of this part accounts for 12% of the total power consumption at the lowest^[1].

We can also see the power consumption wasted by circulating water pump by starting and stopping times of the unit. In the actual operation, the system has the problem that the unit starts and stops frequently, and the unit running condition is poor, which seriously affects the unit performance. In the heating season of 2018, the statistical downtime reached 45%^[1]. When the main engine stops running, the circulating pump is always running at the power frequency. This data is used as the basis for translation.

At present, the experimental system controls the water pump away from the heat pump host. Moreover, when the temperature of the outdoor heat pump host reaches the standard and stops, the circulating water pump will run from 50Hz to 30Hz, and the frequency of

the motor is proportional to the speed of the motor.

$$\text{by } n_1/n_2=f_1/f_2, \text{ know } N_1/N_2=(n_1/n_2)^3 \quad (1)$$

$$N_2=N_1(n_1/n_2)^3=1.1 \ (30/50)^3=0.238\text{kw}$$

It can be seen that the power of running the pump at a low speed is only 0.238kw. In the period when the host heat pump stops running, the energy can be saved as follows:

$$(N_1-N_2) \times d \times 24 \times 45\% = (1.1-0.238) \times 136 \times 24 \times 45\% = 1266 \text{ kW.h}$$

It can be seen that when the power after frequency reduction is 0.238kw, nearly 78% of the original power consumption is saved and the energy saving effect is obvious. If adopted in this way in a large thermal system, the energy saving potential is huge.

4 Influence of frosting conditions

Frost defrost is the biggest obstacle to the application of low temperature air source heat pump in winter. Of course, now that the technology is constantly updated and upgraded, intelligent defrosting is no longer a problem. However, the change of local climatic conditions plays a key role in the formation of frost. If we can make a judgment in advance according to the weather change and implement the established operation plan, it is very necessary to select the low-temperature air source heat pump system and equip it with auxiliary heat source.

At present, the heat pump manufacturers provide products have -30°C, -35°C machine, for the cold region, the temperature is not a problem, compared with the southern region, the cold region in winter relatively dry, low temperature. In the south, the humidity is high and the temperature is relatively high. However, as A heating device, the low-temperature air source heat pump absorbs low-grade energy from outdoor air and transmits heat to the indoor through refrigerant. To make the refrigerant evaporate and absorb heat at low temperature, the outdoor air is subjected to the process of isothermal cooling (A to B) or cooling and dehumidification (A to C), as shown in figure 1.

Fig. 1 surface treatment of outdoor air in heat pump

Theoretically, when the external surface temperature of the evaporative heat exchanger is lower than the dew point temperature of the outdoor air state point, the surface of the heat exchanger will frost (or dew), and the frosting condition is affected by the outdoor dry bulb temperature and relative humidity. You can see this from table 2. In a heating season, at the beginning and end of the heating, the outdoor temperature is relatively high, generally in $5\sim-5^{\circ}\text{C}$ or so, at this time, the outdoor relative humidity on equipment frost impact is small,

only when the relative humidity is close to 100% frost phenomenon occurs. When entering heating medium period, when outdoor temperature is in $-10\sim-20^{\circ}\text{C}$ or so, when outdoor relative humidity is in 80~85% above, just have frost risk. When the outdoor temperature is around $-20\sim-35^{\circ}\text{C}$ and the outdoor relative humidity is over 70~75%^[4,5], the risk of frost. In addition, we find from table 2 that under the same temperature, the lower the outdoor relative humidity is, that is, the drier the air is, the lower the risk of frosting is. Under the same relative humidity, the lower the outdoor temperature is, the smaller the temperature difference between the dry bulb temperature and the dew point temperature corresponding to the relative humidity is, the lower the heat transfer capacity is, and the greater the amount of air required. When the surface temperature of the heat exchanger is lower than the dew point temperature corresponding to the outdoor dry ball temperature, the cooling and dehumidification process occurs, as shown in the process A to C in figure 1, at this time, unit air quality of the air precipitation water is delta d, frost phenomenon occurs.

Table 2 Dew point temperature ($^{\circ}\text{C}$) corresponding to different dry bulb temperature and relative humidity

$\begin{matrix} (^{\circ}\text{C}) \\ \phi \end{matrix}$	5	0	-5	-10	-15	-20	-25	-30	-35
35	-9.2	-12.2	-16.2	-20.3	-24.4	-28.6	-32.8	-37	-41.3
40	-7.5	-12	-14.8	-18.9	-23.1	-27.3	-31.5	-35.8	-40.2
45	-5.2	-9.3	-13.5	-17.7	-21.9	-26.1	-30.4	-34.8	-39.1
50	-4.5	-9.2	-12.3	-16.5	-20.8	-25.1	-29.4	-33.8	-38.2
55	-2.9	-7.1	-11.3	-15.5	-19.8	-24.1	-28.5	-32.9	-37.3
60	-2.1	-6.8	-10.3	-14.6	-18.9	-23.2	-27.6	-32.1	-36.5
65	-0.9	-5.1	-9.4	-13.7	-18	-22.4	-26.8	-31.3	-35.8
70	0	-4.8	-8.5	-12.9	-17.2	-21.7	-26.1	-30.6	-35.1
75	0.8	-3.4	-7.8	-12.1	-16.5	-20.9	-25.4	-	-
80	1.6	-3	-7	-11.4	-15.8	-20.3	-	-	-
85	2.4	-2	-6.3	-10.7	-15.2	-	-	-	-
95	4.3	-0.7	-5	-	-	-	-	-	-
100	5	0	-	-	-	-	-	-	-

Note: the bolded number is the near saturation state at the relative humidity corresponding to different dry bulb temperatures (where the dry bulb temperature is the same as the dew point temperature).

Table 3 saturated relative humidity (ϕ) corresponding to different outdoor dry bulb temperatures

Air dry bulb temperature ($^{\circ}\text{C}$)	5	0	-5	-10	-15	-20	-25	-30	-35
Saturated relative humidity ϕ	100	100	95	91	86	82	78	74.5	71

Under ideal conditions, any outdoor condition is slightly moist air dry bulb temperature, wet bulb temperature, dew point temperature and relative humidity parameters, such as when the outdoor air reaches saturation, is the state points in the line of saturation relative humidity at this point, the outdoor dry bulb temperature, wet bulb temperature and dew point temperature is the same, no longer have the ability to absorb water and air, no redundant moisture will precipitate. At this time, the corresponding low temperature air source heat pump, theoretically is a

working critical point. As shown in table 2, when the outdoor dry bulb temperature is -30°C (assuming the evaporation temperature is -30°C , the actual evaporation temperature is lower than -30°C), and outdoor relative humidity was 70% (the actual corresponding saturated -30°C relative humidity is 74.5%, other corresponding saturated temperature relative humidity are shown in table 3), the state points corresponding to the dew point temperature is -30.6°C , low temperature heat pump surface frost in theory, but are close to a limit value, the low temperature heat pump working conditions are very

bad. The corresponding dewpoint temperature values under other different conditions are shown in table 2.

5 conclusion

Through the experimental research in the two heating seasons, combined with operating data, the analysis of the heat pump installation position and orientation, circulating water pump control / frequency conversion, and frost conditions controlled by the host have a large impact on the energy efficiency of the heat pump unit. Based on theoretical formula calculations and analysis of measured data, the temperature in the south direction is 0.75°C higher than the temperature in the north direction, and the temperature of the first floor in the north direction is 1.25°C higher than the temperature of the sixth floor in the same direction. The heat pump can increase when the air temperature increases by 1K 2.4%; The circulating water pump controlled by the heat pump host was changed from power frequency to frequency conversion to save 78% of the power consumption during the period when the heat pump host is out of service; the frost condition chart can be used to coordinate the configuration and operation of the selected unit and other heat sources. The adjustment or prediction, especially in the extreme conditions of extreme cold regions, protects the unit and enables the unit to exert its

maximum efficiency, providing a reference for the future design of the heat pump system and operation.

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