ANALYSIS OF PERFORMANCE OF AIR SOURCE HEAT PUMP OPERATING IN WINTER

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Abstract Air source heat pump (ASHP) with no cooling water system is more convenient than water-cooled chiller in installation, operation and maintenance, etc. It can serve for building both in summer and in winter without other heat source equipment such as boiler. China has a large territory. She crosses four climate zones. Four seasons can be distinguished easily around the middle and lower reaches of Yangtze River, where it's cold in winter and hot in summer. But in winter, there is no extremely cold day. In this district, it needs cooling in summer and heating in winter. There are many factors in the choice of air-conditioning's cold and heat source. ASHP has become one of the most popular products for its merits. In the paper, the site tests have processed with air-source heat pump operation in some public buildings. And their energy performance has been analyzed. From the point of energy efficiency view, the prospect for the air-source heat pump's wide application is not so excited.

INTRODUCTION

Air source heat pump (ASHP) is widely applied in China, especially in South-China. Because air source heat pump with no cooling water system is more convenient than water-cooled chiller in installation, operation and maintenance, etc. It can serve for building both in summer and in winter without other heat source equipment such as boiler. ASHP can be installed on roof or outside without occupying useful area, which benefits the reduction of building cost by raising the building's utilization ratio. According to our investigation for two hundred public buildings, there are 51.5, about 25.3 percent buildings applying air source heat pumps as their heat and cold sources. Figure 1 shows the application situation for different heat and cold sources in air-conditioning system in Shanghai, China.

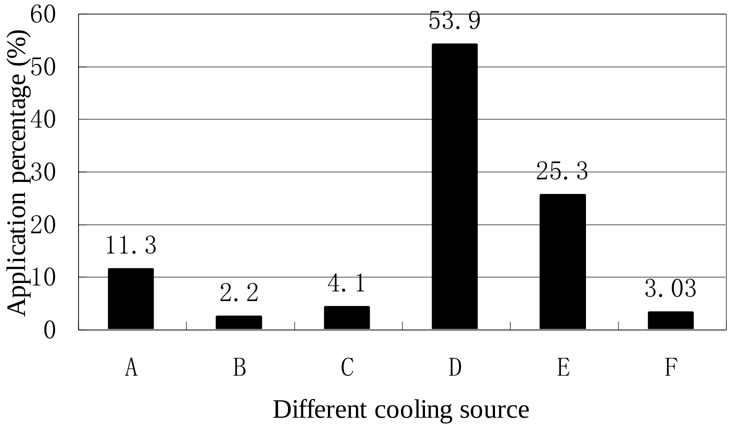

Figure 1 Application Situation of Different Heat and Cold Sources

A---steam lithium bromide absorption chiller B---oil direct-fired lithium bromide absorption chiller C---gas direct-fired lithium bromide chiller D---water-cooled compressing chiller E---air source compressing heat pump F---split unit air conditioner

But how about the operation efficiency of the air source heat pump in application is concerned in the paper. In the paper, the site tests have processed with air-source heat pump operation in some public buildings. And their energy performance has been analyzed. From the point of energy efficiency view, the prospect for the air-source heat pump's wide application is not so excited. The site tests and results analysis are introduced in the paper, also the reason lead to the result is analyzed in the paper.

1. TESTING CONTENTS AND METHODS

The testing of energy consumption is made from two aspects. One is testing the cooling or heat capacity of air source heat pump. The other is testing the energy consumption, which is needed for air source heat pump to produce corresponding cooling or heat capacity. Through testing cooling capacity and energy consumption, we could analyze the working conditions of air source heat pump such as whether its performance and EER is reasonable or does attenuation occurred. If there are problems, we can diagnose and take accordingly measures to make heat pumps working under high efficiency.

We tested the flow rate of chilled or hot water and temperature at inlet and outlet, then calculated cooling or heat capacity according to following formula:

$$Q_0 = C \cdot M \cdot (T_{out} - T_{in}) \tag{1}$$

Where

Q_0 — cooling capacity of chiller，kW；

C — specific heat of chilled water，kJ/kg℃；

T_{in} — inlet temperature of hot water，℃；

T_{out} — outlet temperature of hot water，℃；

M — flow quantity of hot water，kg/S。

Ultrasonic flow-rate meter was used to test the flow rate of hot water, whose two sensors were put on the exterior wall of hot water pipes and did not need to contact water. Some length straight pipes are needed on tested pipes.

We test the electricity parameters of air source heat pump by multimeter and got the data of ampere, voltage and power factor, then calculated its energy consumption through following formula:

$$P = \sqrt{3} \cdot U \cdot I \cdot COS\phi \tag{2}$$

Where

P — electricity consumption of air source heat pump，kW；

U — voltage，V；

I — ampere，A；

COS Φ — power factor。

The Energy Efficiency of Performance(or ratio) (EER) is calculated by the following formula:

$$EER = \frac{Q_0}{P} \tag{3}$$

Where:

EERenergy performance;

Q_0 — heat capacity, kW;

P — electricity consumption of air source heat pump, kW.

2. ENERGY EFFICIENCY WHEN HEATING BY ASHP

2.1 ASHP in D Building

A building is an office building with seven floors. There are three units air source heat pumps placed on roof. Each air source heat pump has 285 kW heat capacity and consumes 83.2 kW electricity when it is applied to offer heat. The heat pumps are used as cold sources in summer and as heat sources in winter for the air-conditioning system in A building.

Figure 2 shows EER changed with time on the test day.

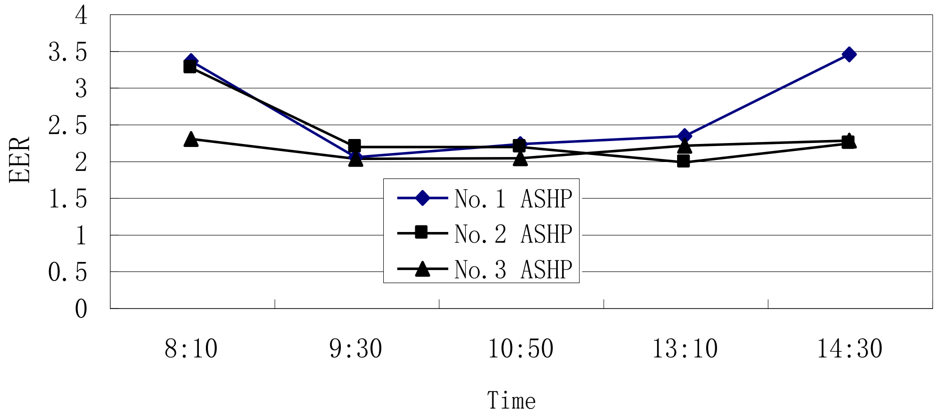

Figure 2 Change of Three ASHPS' EER with Time

On the test day, three air source heat pump were put into operation at the same time. The outside air temperature (OAT) is 1~5℃ on the day. That day, No.1 unit's maximum EER is 3.44. At the same time, the supplying water temperature is 41℃, the temperature difference between supplying & returning water is 3℃. Figure 3 shows EER of No.1 ASHP changed with OAT. From the figure, even the EER of No. 1 ASHP was lower than the value given by the stylebook on the same operation condition. No.2 ASHP's maximum EER is 2.29 and its supplying water temperature is 42℃. Those of No.3 ASHP are 3.29 and 41℃. Comparing the three units with each other, we can find that the EER of No.1 ASHP is the maximum, No.2 ASHP's is the next and No.3 ASHP's is the minimum. In general, the temperature difference between supplying & returning water of the three units are all less than 5℃. Why were the EERs of No.2, No.3 and even No.1 ASHPs relatively low? Maybe it is caused by some factors. One possible reason is that the indoor heat load reduced with the OAT rising. However, the quantity of the operating units is more than that are needed actually. It made ASHP operate under partial load all the time. The energy consumption of compressor is quite a few. Therefore, the EER of ASHP is low. Another

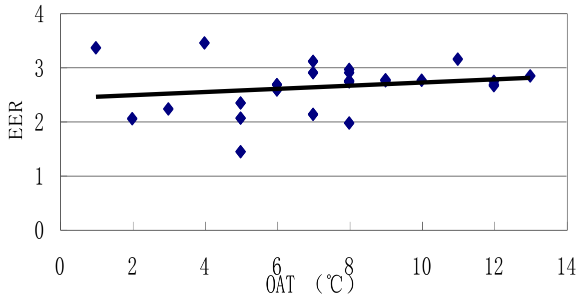

Figure 3 Change of No.1 unit's EER under different OAT

possible reason is that the units didn't operate normally. Even there is fault existing probably, such as the scarcity of the refrigerant, the not good efficiency of evaporator's heat transfer, etc. Another possible reason is that the control system of ASHP hasn't been designed properly. And the energy regulation system doesn't work well. Furthermore, probably the heat amount listed in the brochure is higher than actual condition.

2.2 ASHPS Applied in B Building

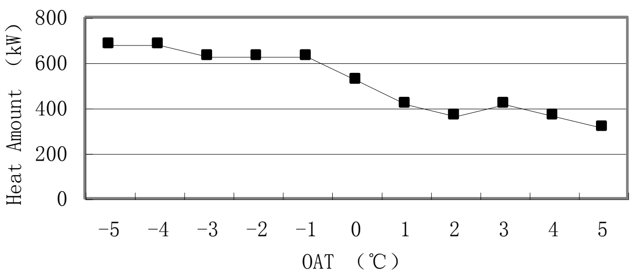

Figure 4 Relation between Heat Amount and OAT

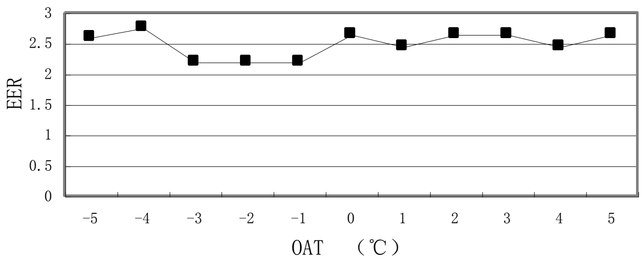

Figure 5 Change of No.3 ASHP's EER with OAT

As an office building with 16 floors, B building is 7000m^2 large (concluding 5000m^2 for A.C.). Three ASHPs have been selected to work as the heat and cold source of the air-conditioning system. Each can offer 349kW heat capacity and consume 103kW electricity when it is applied to produce heat. The units, above which there are some covers to protect from rain, lie on the roof. Figure 4 shows heat capacity of three ASHPs changes with outside air temperature on the test day. Figure 5 shows EER of No.3 ASHP changes with OAT on the test day.

It's easy to find that with the OAT's rising heat amount reduced. Maybe it is caused by the decrease of the indoor cold load. When the OAT was very low, heat amount was high. Because heat amount needed increases with the OAT's dropping. Once the OAT was low, the supplying water temperature was low. For example, the supplying water temperature was only 26℃ when the OAT was –6~-3℃. But the EER (2.66) wasn't too low.

When the OAT was low to –5~-4℃, the EER of ASHP was high on the contrary. But then, the supplying water temperature was low and heat amount was high. When the OAT is –5 ℃, supplying water temperature is 35℃, nominal heat amount is 276kW, electricity consumption is

86kW, EER is 3.2 from the ASHP stylebook. We can arrive at the result from the data reflecting the actual condition that with the same OAT and the supplying water temperature, the heat amount of every unit is 262kW, electric consumption is 95~105kW, EER is 2.45~2.8. These data prove that the units worked under the full load almost. Compared with the full load, the efficiency of the partial load is lower. The nominal heat amount is 330kw, electricity consumption is 94.2 kW , EER is 3.5 when the OAT is 4℃, supplying water temperature is 40℃. In fact, when the OAT is more than 2 ℃, heat amount of every unit is 157kw, electricity consumption is 60 kW, EER is 2.6. It proves that the performance of ASHP under partial load is not as fine as under full load. The contradiction exists in winter and is impossible to avoid. When the OAT grows, the ability of ASHP's heating rises. But then the indoor cold load reduces. It leads to the surplus of heat amount. In a month and a half which is coldest in last winter, heat amount of every unit is 157~262kW, EER is 2.2 ~2.76. It's obvious that the EER is higher when the OAT is more than 0℃ than it is when the OAT is less than 0℃. So we can conclude that the OAT has a great influence on the performance of the ASHP. On the other hand, relative humidity can also have influence on unit. Evaporator is easy to frost when relative humidity is high even if the OAT isn't quite high. Frost will make heat amount reduce. If evaporator deposits frost seriously, ASHP will be forced to stop working. In Nanjing, Jiangsu Province, China, the average of relative humidity in winter is 75% or so. But when the OAT is less than 0℃, relative humidity is more than 70%. The heat pumps can defrost automatically, so the three units haven't work abnormally because of frost.

2.3 ASHPS in C Building

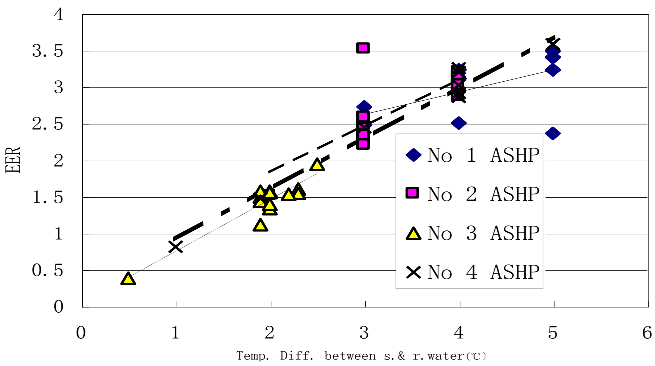

Figure 6 EER Changes with Temp. Diff. betwen S. & R. Water

C building is a hospital, which has applied 6 air source heat pump as its heat and cold sources for its air-conditioning system. Each ASHP can offer 680 kW heat capacity and consume 200kW electricity on the rated operation condition when it is used to produce heat. Figure 6 shows the EER changes with temperature difference between supply and between water.

On the test day, there were 4 ASHPs put into operation. From Figure 6, we can see that EER of any individual heat pump (the same type, of course) shows a similar relation to the change of temperature difference. But EER differs considerably though all of the heat pumps work at the same temperature difference. No.1 unit runs at a higher temperature difference, while No.2 unit works at the lowest temperature difference. Figure 6 shows that the highest temperature difference of No.2 unit is 2.5 ℃, and the lowest is just 0.5 ℃. But the two loops of No.2 unit runs invariably during the measuring day. Maybe the operating situation of No.2 unit isn't good. Its EER under partial heat load operation is much lower than the one provided in the brochure. The temperature difference between the supplying & returning water represents heat load indirectly. Hence it indicates that this type heat pump performs poorly under partial heat load operation.

3. CONCLUSIONS

From the above description, the following conclusions have been concluded:

1) The air source heat pump is very convenient for use. Not only can it be cold source in summer, but also be heat source in winter. It is widely applied in China, especially in two sides of Yangtze River, China.
2) From the site test, the energy of ASHP is not so excited. Many facts maybe cause the results. Firstly, the ASHP may not work properly, even may has wrongs with it. Secondly, the automatic control may be not very proper. Thirdly, the operator may have less experience to operate the ASHP and so on.
3) To improve the ASHP operation energy efficiency, especially improve the energy efficiency of ASHP operating under partial condition. From the test results, the EER of partial condition is bad in some extent. But the ASHP works under partial conditions in a majority of time.
4) How to improve the efficiency of heat pump under partial load needs deep research.

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