Application and analysis of low temperature air source heat pump heating system in Cold Area

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Abstract. A low temperature air source heat pump (ASHP) heating system of residential building in cold area was designed and tested. The operating characteristics of the low temperature ASHP heating system in the typical day, typical month and the whole heating season were analyzed. The system energy saving performance in the whole heating season was also calculated. The results showed that the low temperature ASHP system operated stably in cold area and has energy-saving effect.

1. Introduction
In recent years, the “coal to electricity” project has effectively improved air quality during the heating season in northern China. ASHP is a heat pump system that obtained heat energy from low temperature air heat based on the inverse Carnot Principle. A small amount of electric energy was consumed as driving energy and a large amount of low temperature heat energy in the air was converted into high temperature heat energy. Low temperature ASHP can operate stably and efficiently in cold areas. An example of ASHP heating in Shandong was analyzed in this paper.

2. The system design
A 65% energy-saving residential buildings was studied in cold areas. The total building area is about 5966 m², and the heating area is about 4645 m². The building height is 20.5 m, including a basement floor for storage, seven floors above ground. The heating terminal was floor radiant heating. The heating time is from November 16 to March 15 of the following year.

Through simulation analysis, the hourly heat load data of the whole heating season of the building is obtained. The maximum heat load of the whole heating season is about 220 KW, and the corresponding ambient temperature is -11.18°C. When the local outdoor design temperature is about -7°C, the corresponding heat load is about 169.55KW. The cumulative total heat load in the whole heating season is about 271,240.6 KWh.

Low temperature ASHP heating system is composed of a heat pump unit, Power cycle device, hydrating constant pressure device, and user end. The interior end of the study building is floor panel heating. Taking the characteristics of low temperature ASHP heating and radiant floor heating into account, supply water temperature and the difference of temperature difference between supply and return water is 45°C and 5°C respectively. The main equipment types and parameters of the heating system are shown in Table 1.
Table 1. Main Type Selection Equipment Model Table

| Number | Name                      | Specification and type | Quantity |
|--------|---------------------------|------------------------|----------|
| 1      | low temperature ASHP     | 84.2KW(-12℃)           | 2        |
| 2      | circulating water pump    | Q=44m³/h H=28M         | 2        |
| 3      | make-up water pump        | 1.2m³/h H=32m          | 2        |
| 4      | demineralized water tank  | V=1m³                  | 1        |
| 5      | fully-automatic water softener | Q=1m³/h    | 1        |

To adjust the system operation in real-time and analyze the system operation characteristics, the operating data of the system, such as pressure, temperature testing, and power consumption collecting are finished by PLC automatic control system. Figure 1 is the process and detection system diagram.

Figure 1. Process and Test System Diagram

3. Analysis of operation characteristics of low temperature ASHP heating system

The heating period studied in this paper is from November 15 to March 10 the following year.

The operating characteristics of the low temperature ASHP heating system in typical days, typical months, and the whole heating season are respectively analyzed in the following.

3.1. Analysis of operation characteristics of typical days

According to the way of low outdoor temperature, this paper selects a heating natural day as a typical day to analyze the operation characteristics of low temperature ASHP heating system. The temperature of supply and return water, the temperature difference between supply and return water, the unit COP, and system COP with time in 24 hours are studied.

The lowest outdoor temperature in a typical day is -10.38℃, which occurs at 7 a.m. The highest outdoor temperature was -2.40℃, which appeared at 2 p.m. The average outdoor temperature is -6.45℃. The outdoor temperature was low all day and typical days are cold days in the heating period. The operating characteristics of the system are shown in Figure 2 and Figure 3.
Figure 2 shows the variation of the average supply and return water temperature of the low temperature ASHP heating system with time in a typical day. In the typical day, the deviation of water supply temperature is ±0.7℃, the water supply temperature is basically stable, which indicates that the heating capacity of the system is stable. The return water temperature deviation of ±0.6℃ means that the return water temperature tends to be stable. It shows that the indoor temperature fluctuation of the building is small and the heating effect is stable. The maximum temperature difference between supply and return water of the system is 5.7℃, the minimum is 4.1℃, and the average temperature difference between supply and return water is 4.8℃. The variation trend of the temperature difference between supply and return water is opposite to the variation trend of outdoor temperature, that is, it is the same as the variation trend of building thermal load.

Figure 3 shows the variation of hourly unit COP and hourly system COP of a typical daily low loop temperature ASHP heating system with time. The maximum and minimum COP of the typical daily hourly unit are 2.88 and 2.53, which means that the COP of the unit fluctuates greatly, and the heating performance of the heat pump unit is greatly affected by the outdoor ambient temperature. The maximum value of the hourly system COP is 2.64, and the minimum value is 2.38. From the above analysis, it can be concluded that the low temperature ASHP heating system can provide high-efficiency heating under the cold condition, and the energy saving is obvious, the higher temperature, the better energy saving.

3.2. Analysis of typical monthly operating characteristics
This paper takes January as a typical month to analyze the operation characteristics of low temperature ASHP heating system. The main daily average performance parameters of the low temperature ASHP heating system were studied with the change of time in the 31 days of a typical month.

The lowest average daily outdoor temperature in a typical month is -6.45℃, and the highest is 2.71℃. The overall temperature is low. The operating characteristics of a typical monthly low loop temperature ASHP heating system are shown in Figure 4 and Figure 5.
Figure 4 shows the variation of supply and return water temperature with time in a typical monthly low loop temperature ASHP heating system. The average water supply temperature is 37.0°C, the water supply temperature has a certain fluctuation but basically stable, indicating that the system has a wide range of heating and heating capacity is stable. The return water temperature deviation is ±1.6°C, the return water temperature is stable, indicating that the heating effect of the system is stable. Careful observation shows that the variation trend of the average daily supply and return water temperature of the heat pump heating system is consistent, but the variation trend of the average daily supply and return water temperature is much gentler than that of the outdoor temperature, indicating that the system makes full use of the thermal inertia of the building envelope to maintain the stability of the indoor temperature, which is conducive to the energy saving of the system. From the above analysis, it can be concluded that in the typical month of the heating season in January, when the outdoor temperature changes greatly and the whole condition is cold, the low ring temperature ASHP heating system can provide heating with a wide range and stable effect.

Figure 5 shows the variation of COP of the typical monthly low loop temperature ASHP heating system and COP of daily average system with time. In a typical month, the maximum COP of the heat pump unit is 3.37, the minimum is 2.61, and the average is 2.98. The maximum, minimum, and average COP of the daily system was 3.10, 2.42, and 2.76 respectively. It can be seen from Figure 5 that the variation trend of COP of the daily average heat pump unit and the COP of the daily average system is the same as that of the outdoor temperature, which is completely in line with the performance characteristics of the ASHP. When the outdoor temperature is higher, the heating performance is better and the energy saving is more obvious. From the above analysis, it can be concluded that the low ring temperature ASHP heating system can provide heating continuously and efficiently in the coldest months, and the energy-saving performance is obvious.

3.3. Analysis of the operating characteristics of the whole heating season

For the whole heating season, this paper mainly analyzes the monthly cumulative heat production, monthly cumulative power consumption, and monthly average COP of the low loop temperature ASHP heating system. This paper is divided into heating will throughout the heating season in chronological order on March 1, heating month 2, heating, heating month 4, by collecting data for each separate accounting on heating of the heat pump units in total electricity consumption, system month accumulative total power consumption and month accumulative total calories, and calculated the monthly average heat pump COP and month average system COP. Figure 6 shows the monthly change in electricity consumption. Figure 7 shows the monthly change of average COP.

![Figure 6. Cumulative system power consumption, monthly cumulative heat pump unit power consumption monthly changes](image)

![Figure 7. Monthly COP of the system and monthly COP of the heat pump unit changes month by month](image)

It can be seen from Figure 6 that the power consumption first increases and then decreases. The power consumption in heating months 2 and 3 is relatively high, which is caused by the cold climate in heating months 2 and 3 and a large amount of heat needed. The cumulative power consumption of the heat pump units in the four heating months is 19034.9kWh, 27993.1kWh, 26888.4kWh, and
17856.3kWh respectively, and the cumulative power consumption of the system in the four months is 21501.2kWh, 30934.4kWh, 29577.3kWh, and 20291.2kWh respectively. To do the heat pump unit power consumption and system power consumption ratio can be concluded that the proportion of total energy consumption of heat pump units of energy consumption system, four heating energy consumption of heat pump units in the system total energy consumption of the proportion of 88.5%, 90.9%, 90.5%, and 88.0% respectively, can be seen in the early and late period of the heating season heat pump units of high energy consumption, heating mid-season is relatively low, this is due to the heat pump units with the loss of the outdoor air temperature heating efficiency is low, and the power consumption will increase, and the other equipment system energy consumption along with the change of outdoor temperature is very small, so even though as the outdoor temperature to reduce the whole heating system, the total power consumption will increase.

It can be seen from Figure 7 that both the COP of the heat pump unit and the COP of the system show a trend of decreasing first and then increasing, which is consistent with the change of the climate environment. The COP of the heat pump unit and the COP of the system on January 1 were 3.26 and 3.01, respectively. The month 2 of heating was 2.98 and 2.76, respectively.3.03 and 2.80 in March for heating, respectively; The value of heating in April was 3.32 and 3.08, respectively. In the whole heating season, the average COP of heat pump unit and the average COP of system are 3.15 and 2.91 respectively. The heating performance coefficient of this system is relatively high overall. From the above analysis, it can be concluded that the heating performance of the low temperature ASHP heating system in the whole heating season is stable and efficient, with obvious energy saving.

4. Conclusions
(1) Under the low temperature condition with typical outdoor average temperature of -6.45°C, the average backwater temperature of the system is 37.8°C/33.0°C, the average backwater temperature difference is 4.8°C, the low ring temperature ASHP heating system has sufficient heating capacity and stable heating.

(2) However, the average daily water supply temperature of the system is stable, the backwater temperature fluctuates little, the heating system of low ring temperature ASHP can provide a wide range of heating, the effect is stable, the maximum COP value of the system is 3.10, the minimum value is 2.42, the average value is 2.76, the heating system of low ring temperature ASHP can provide heating continuously and efficiently in the coldest month, and the energy-saving is remarkable.

(3) The average heat pump unit COP and the average system COP are 3.15,2.91 for the whole heating season. The performance coefficient of the unit and system is high. The low ambient temperature ASHP heating system provides efficient heating in this area.

Acknowledgments
Supported by Key Research and Development Projects of Shandong Province (2019GGX103046, 2019GGX103013).

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