14th IEA Heat Pump Conference
15-18 May 2023, Chicago, Illinois

Case Study of the Largest Air Source Heat Pumps Central Heating Project in China

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Abstract

This paper summarizes the best practices for Air Source Heat Pump (ASHP) central heating systems in large-scale residential buildings. Central heating of residential buildings in northern China typically depends on coal-burning power plants, which are the main sources of reducing such pollution as well as carbon emissions. The project described in this paper is one biggest ongoing ASHP heating projects in the world. More than 1,200 units of ASHPs were deployed as heating sources in northern China, heating approximately 4 million square meters of living spaces in large residential buildings. Various parameters were monitored and collected over about 120 days during the heating season from 2019 to 2020. Operating costs and carbon dioxide emissions were measured and compared to the corresponding figures for equivalent heating by other systems. It is demonstrated that ASHP systems are well suited for meeting the heating requirements of this region while reducing operating costs and greenhouse gas emissions.

Keywords: air sources heat pump, large scale central heating project, carbon reduction.

1. Introduction

The heating project in Zhao County is located in Hebei province, north China, it is a typical cold winter area, and space heating in winter is managed by the government. The heat source that came from two coal-burning power plant caused serious air pollution significantly. In 2019, the local government decided to replace the coal-burning power plants with ASHP to reduce running cost and air pollution. Therefore, 1,200 ASHP units (input power is 60HP for each) are used for a 4.07 million square meters heating area; the terminals in the buildings are radiator and floor heating. The operation data of the 2018-2019 heating season provide favorable support for the heating system renovation. To fit the existing heating pipe network the whole heating project is designed to build 42 distributed air source heat pump stations with the 1200 units ASHP for heat supply. The old heating pipe network consists of two coal-fired power plants (A and B) as shown in Fig. 1(a), and the ASHP heating stations as shown in Fig. 1(b). Fig. 2 illustrates the Beling temple station and the Lichun station with ASHP units.

For large-scale ASHP projects, multiple sets of units placed together will impact the performance of the unit is a big problem. In the Zhao County project, many sites faced this challenge. There are also many other factors that affect the sites of the air source heat pump heat source selection, distributed heat source arrangement for the urban heating project is recommended to minimize the heat loss of the pipe network.

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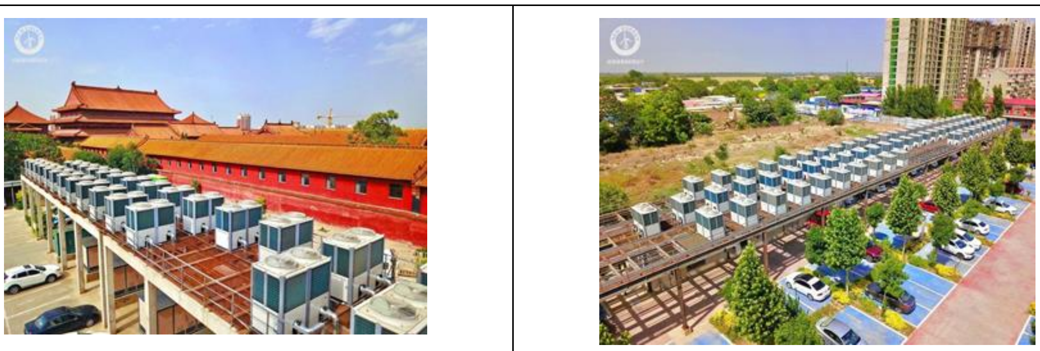
(a) The old heating pipe network (red ones) by two coal burning power plants (A and B)

(b) The ASHP heating stations (green ones) distribution with1200 units

Fig.1. The old heating pipe network and the new ASHP heating stations in Zhao County.



(a) Beling temple station with ASHP units

(b) Lichun station with ASHP units

Fig.2. The layout of ASHP units in the two stations.

2. Project overview

2.1. The system configuration scheme

The heat load of this project was calculated using the real-time calculation method (secondary stations with monitoring conditions) and the area index method (secondary stations without monitoring conditions). The average heat load during the heating period was calculated to be 137.9 MW. Combining with the heating load and development of the urban area of Zhao County and the fuel characteristics, 1200 ASHP units (120 KW of heat production per unit under heating condition) were selected for this project, and the development end was reserved in the heat source to meet the demand of future heating heat load growth. Low temperature water was adopted as the heating medium, with the supply and return water temperature of 55 ℃/45 ℃ at the end of radiator and 45 ℃/35 ℃ at the end of floor heating. The system configuration scheme of a station is shown in Fig. 3. Considering factors such as system drainage, the make-up water rate of this project was taken as 1%-2%, and the make-up water pump was used for variable frequency continuous pressure fixing.

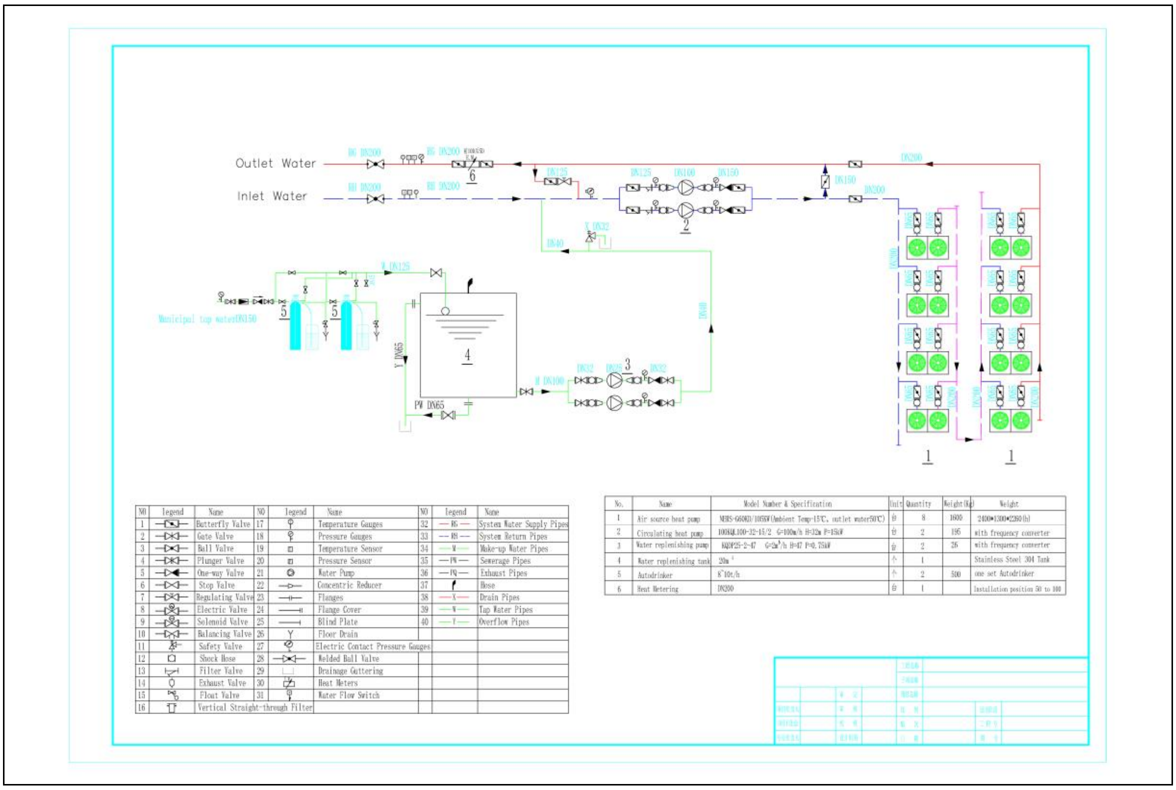
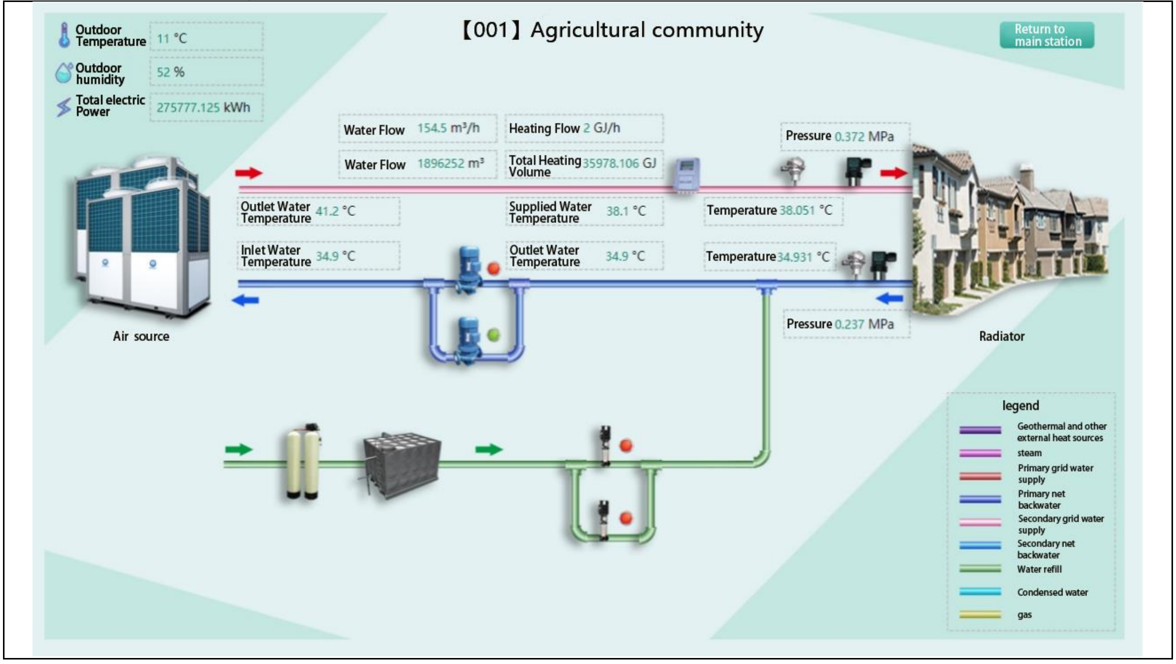


Fig.3. The system configuration scheme of a station in the large ASHP heating project.

2.2. The system operation scheme

The system adopts group control automatic management, which can realize to present the site water temperature and operation status of heat pump unit on the computer and cell phone, and also adjust the site parameters and remote switch operation. As shown in Fig. 4, the low-temperature hot water produced by the air source heat pump is transported to the heat users through the pipeline, and the whole heating process is monitored in its entirety.



【001】Agricultural community

Outdoor Temperature 11 °C

Outdoor humidity 52 %

Total electric Power 275777.125 kWh

Water Flow 154.5 m³/h

Heating Flow 2 GJ/h

Water Flow 1896252 m³

Total Heating Volume 35978.106 GJ

Pressure 0.372 MPa

Outlet Water Temperature 41.2 °C

Supplied Water Temperature 38.1 °C

Temperature 38.051 °C

Inlet Water Temperature 34.9 °C

Outlet Water Temperature 34.9 °C

Temperature 34.931 °C

Pressure 0.237 MPa

Fig.4. operation scheme and monitoring data for key parameters of an ASHP station.

3. Operating data and unit performance analysis

3.1. The system performance test data

The ASHP unit in the project has 4 compressors systems with the same configuration for each one as shown in Fig. 5.

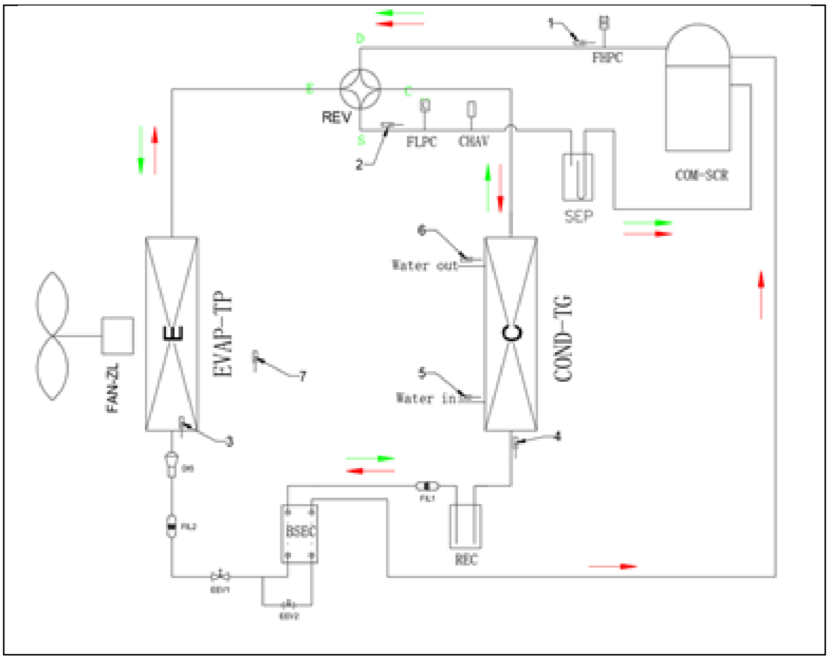


Fig.5. The system configuration scheme of the unit.

The system performance test data under the different ambient temperatures and different outlet temperatures of the ASHP unit has been listed in Table 1.

Table 1 The performance test data of the ASHP unit in the test lab.

NO.	Outlet water temperature (℃)	Ambient Temperature -5 ℃		Ambient Temperature -12 ℃		Ambient Temperature -20 ℃	
		Heating capacity (kW)	COP	Heating capacity (kW)	COP	Heating capacity (kW)	COP
1	41	130.5	3.03	112	2.62	94	2.32
2	45	131.05	2.85	112.87	2.46	95.77	2.11
3	50	133.5	2.55	114	2.18	98	1.91
4	55	135.2	2.45	116	2.12	100	1.8

3.2. The unit performance analysis

Based on the Fig.4 scheme, the monitoring data of the key parameters for corresponding systems such as outside ambient temperature, humidity, total electric energy consumption, transient flow rate of the heating water, and total flow rate of the heating water, the temperature of inlet and outlet water, the pressure of inlet and outlet water, the water pump running status and so on.

The heating capacity of the unit is calculated according to Eq. (1).

$$Q = \frac{c\rho V\left(t_g - t_h\right)}{3600} \quad (1)$$

Where, Q is the heating capacity of the unit, ρ is the density of the water, V is the water flow rate, t_g and t_h are the supply and return water temperature, respectively.

The heat dissipation of the cable comes from the heat loss of the current-carrying conductor. The single cable power loss can be calculated according to Eq. (2).

$$Q' = \frac{I^2 R}{A} \tag{2}$$

Where, Q' is the power loss, I is the cable current flow, A is the cable cross-sectional area, and R is the resistance value per meter of cable.

The coefficient of performance (COP) of the unit is calculated by Eq. (3).

$$COP = \frac{Q}{W} \tag{3}$$

Where, COP is the coefficient of performance of the heat pump unit, W is the power consumption of the heat pump unit.

The key operating parameters of the system and the performance of the unit are shown in Table 2.

Table 2 The key parameters and the COP for a unit in the 5 stations.

Contents	System 1	System 2	System 3	System 4	System 5
ASHP station name	Lichun school	Shihao	Shuiliju	Dianli 3	Sichangxiqu
Ambient temperature (℃)	-3.7	0	2.2	4.2	7.3
Inlet temperature (℃)	44	42.1	46.4	42.8	43.1
Outlet temperature (℃)	48.5	47.3	52.9	51.4	49.8
Water flow rate (m^3 /h)	28.336	24.194	21.99	15.868	20.44
Heating power（kW）	148.27	146.29	166.2	158.68	159.31
Total electric power input（kW）	52.13	51	55.52	53.6	54.67
Heating COP（kW/kW)	2.84	2.87	2.99	2.96	2.91

According to the monitoring data, the ambient temperatures in the heating season 2019-2020 are listed in the table 3, in which the energy consumed by water pumps and the heat losses from the pipes are not included. The percentage of each ambient temperature zone has been shown in the Fig. 6.

Table 3 The ambient temperature and corresponding data in the heating season 2019-2020.

Ambient Temp. (℃)	Hours (h)	Peak time (h)	Off peak time (h)	COP
-15~-10	12	6	6	2.26
-10~-5	90	52.5	37.5	2.47
-5~0	891	519.75	371.25	2.66
0~5	1068	623	445	2.88
5~10	597	348.25	248.75	3.16
10~15	234	136.5	97.5	3.55
15~20	30	17.5	12.5	3.96
20~25	6	3.5	2.5	4.37

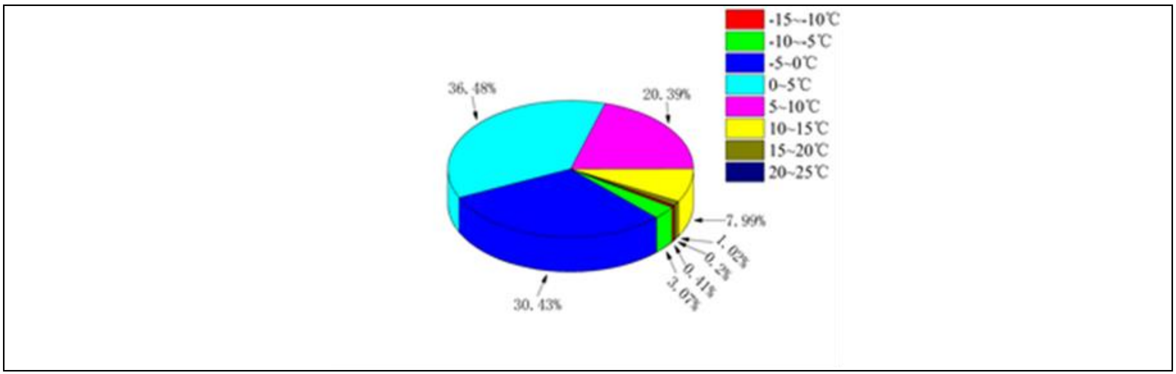


Fig.6. The percentages of each ambient temperature zone.

3.3. Air source heat pump for low ambient zone space heating

Air source heat pumps for heating in cold areas will face many challenges for efficiency and reliability, vapor injection technology for compressors of ASHP unit is a solution to resolve these issues. According to the winter climate record data of Zhao County, the lowest ambient temperature goes to -15 ℃.

Vapor inject technology brings great benefits for ASHP heating in cold ambient conditions. According to the lab test result by Emerson Climate technology, it shows 21% - 40% heating capacity improvement and 7% - 22% efficiency improvement. (Table 4)

Table 4 Vapor injection technology benefits.

Ambient temperature (℃)	Heating capacities improve (%)	Efficiency improves (%)
7	21%	7%
2	23%	6%
-7	37%	16%
-12	40%	22%

Vapor injection technology also can improve the reliability of the heat pump unit, it allows the system to be used in a -30℃ ambient area and deliver high enough temperature water even for radiators. The envelop of the compressor in Figure 7 shows the improvement.

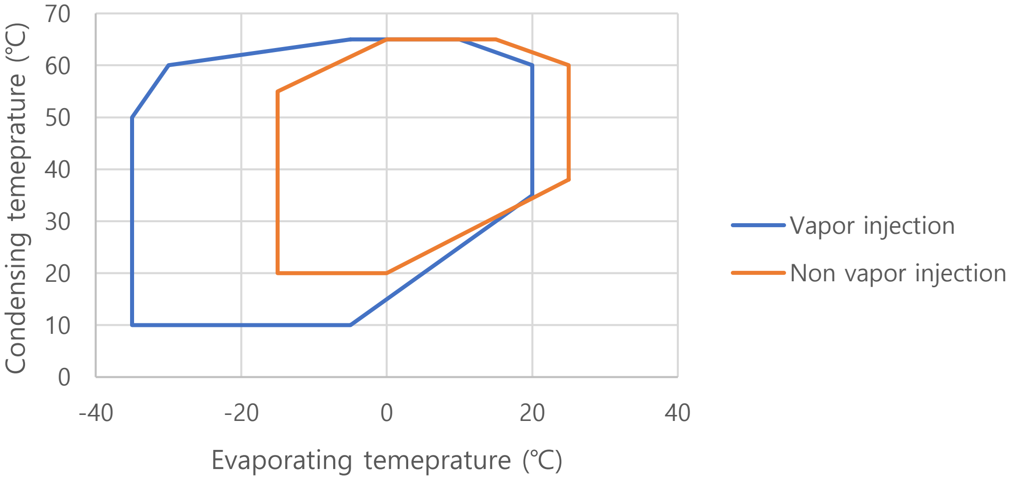


Fig.7. Compressor envelope with and without vapor injection.

4. Heating project optimization

The project is large in scale, short in the cycle, complex at the end, and diverse in construction conditions. How to accurately divide district heating in a complex on-site environment, how to solve the cold island effect and ensure that the selected air source heat pump can exert its maximum performance, how to solve the noise problem, how to achieve the pre-designed control effect, etc. are very critical to ensure that the overall project can meet the requirements of high efficiency, stability, and energy saving. According to the actual specific situation, from design to product, the manufacturer New Energy has repeatedly improved, tested, adjusted, and optimized the unit and the installation.

4.1. Equipment performance matching and tuning optimization

a. Environmental climate is a key factor affecting the use of air-source heat pumps, which determines the initial investment and operating costs of the project, as well as the performance advantages of ASHP. At the beginning of the project design, the historical climate and environmental characteristics of Zhao County were investigated, and make the analysis of the data as shown in Fig. 6.

b. “Cold Island” effect in the large ASHP heating project is a common issue if the air circulation around the ASHP units is not optimized. In order to ensure the good circulation of the air around the units, all the stations have been designed as frame structures with a height of above about 8 meters from the ground, so that the cold air from the units will flow to bottom and other open spaces. Besides, the layout of the units in each station is in line and has a max. 2 or 3 units in the row direction. In this way, the cold island effect in the project is avoided. Refers to Fig. 2.

4.2. Noise reduction

Large scale ASHP heating project could have higher noise for the environment. It is important of sound reduction for this heating project. Sound insulation wall (Fig. 8) is installed on field to reduce the noise impact.

Fig. 8. Noise insulation wall.

4.3. Radiator and floor heating combination

To get same heating performance from the terminals, the water temperature in the radiator will be higher than in floor heating. The hot water temperature leaves the radiator still is high enough for floor heating. But the water quantity for floor heating is bigger than the radiator. Some additional equipment and pipe are needed to balance the water system. Fig. 9 shows the scheme of the combination of the radiator and floor heating.

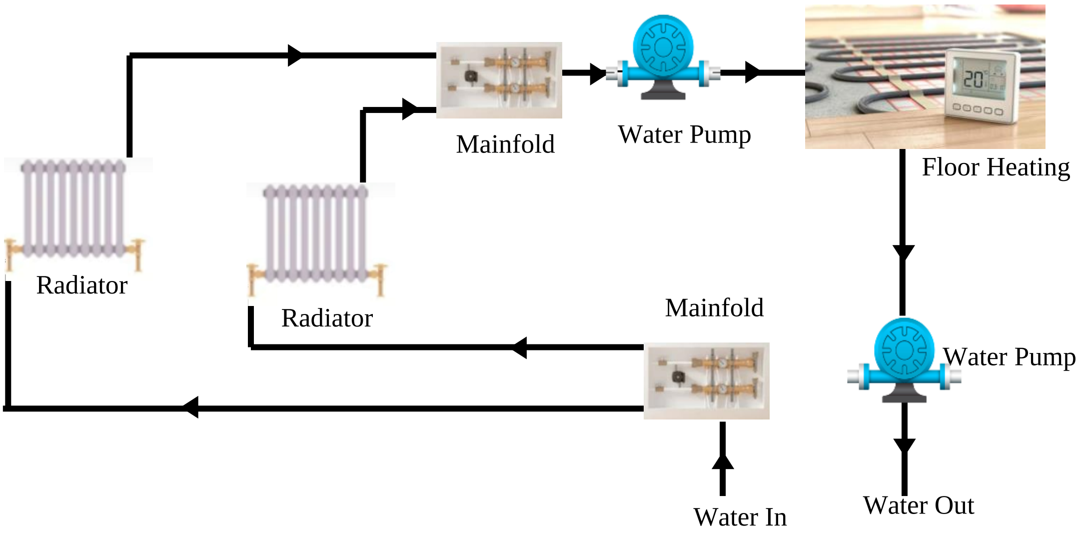
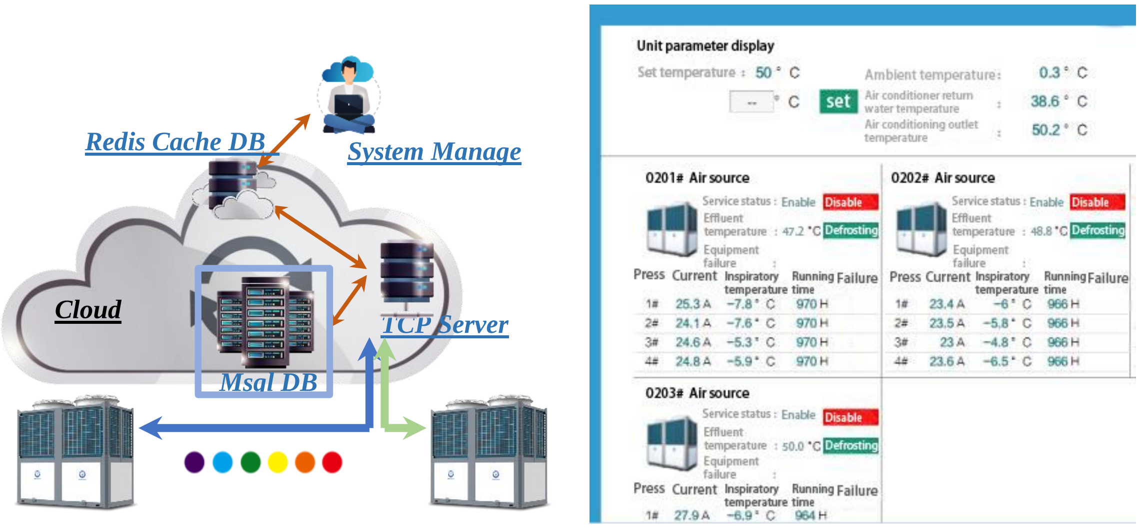


Fig.9. Scheme of radiator and floor heating combination.

4.4. System control

Heating load is determined by ambient temperature and residential behavior, it means the heating capacity requirement constantly changes. The management of 1,200 units ASHP with a higher system performance is important for energy saving. With IoT technology, depending on the temperature of outlet water and return water, automatically adjust the ASHPs for a better system efficiency. Fig. 10 shows the scheme of system control and interface.



Unit parameter display

Set temperature : 50 ° C

-- ° C

Ambient temperature: 0.3 ° C

Air conditioner return water temperature : 38.6 ° C

Air conditioning outlet temperature : 50.2 ° C

0201# Air source

Service status : Enable Disable

Effluent temperature : 47.2 °C Defrosting

Equipment failure :

Press	Current	Inspiratory temperature	Running time	Failure
1#	25.3 A	−7.8 ° C	970 H	
2#	24.1 A	−7.6 ° C	970 H	
3#	24.6 A	−5.3 ° C	970 H	
4#	24.8 A	−5.9 ° C	970 H	

0202# Air source

Service status : Enable Disable

Effluent temperature : 48.8 °C Defrosting

Equipment failure :

Press	Current	Inspiratory temperature	Running time	Failure
1#	23.4 A	−6 ° C	966 H	
2#	23.5 A	−5.8 ° C	966 H	
3#	23 A	−4.8 ° C	966 H	
4#	23.6 A	−6.5 ° C	966 H	

0203# Air source

Service status : Enable Disable

Effluent temperature : 50.0 °C Defrosting

Equipment failure :

Press	Current	Inspiratory temperature	Running time	Failure
1#	27.9 A	−6.9 ° C	964 H	

Fig. 10. System control and interface.

5. The economic and environmental analysis

5.1. Economic calculation

According to the statistical data from the monitoring system of the whole project, the total electric energy consumption in the heating season of 2019-2020 is 100.37 million kWh in the project. The average electrical energy consumption is 30.88 kWh per square meter. The detail data for economy calculation is as in Table 5.

Table 5 economy calculation for a heating season of 2019-2020.

Actual heating area	km^2	3250
Total electrical energy cons.	Mil. kWh	100.37
Total water consumption	ton	155678
Total cost paid	k CNY	43000
Ave. electric energy consumption	kWh/ m^2	30.88
The average price of the power	CNY/kWh	0.43
Average Operation cost	CNY/ m^2	12.23

In the same project, about 220k square meter area lack of electrical power is heated with gas boilers. The average heating cost of the area is 27.27 CNY/ m^2 for the heating season 2019-2020, more than twice of ASHP heating cost.

5.2. Cost saving

Total actual heating area in 2019-2020 heating season is 3.25 million square meters, according to the data recorded in cloud, comparing with another heating project with gas boiler that located in Zhao County as well, the running cost has more than 50% saving. Table 6 shows the comparison:

Table 6 Running cost comparison.

	ASHP	Gas boiler
Energy cost (million CNY)	43	6
Heating area (m^2)	3.25	0.22
CNY/ m^2	13.23	27.27

5.3. CO2 emission reduction

Air source heat pump is recognized as a green technology which can collect heat energy in the air to heat indoor space. It can reduce the CO$_2$ emission by replacing coal boiler. Comparing with gas boiler, the running cost is lower.

Ambient temperature has great impact on the ASHP efficiency, according to the climate bin data of Zhao County and the COP of ASHP under different ambient temperature, the average COP is 2.93 for whole heating season. Fig. 11 shows the detail data of ambient condition of Zhao County and COP of ASHP.

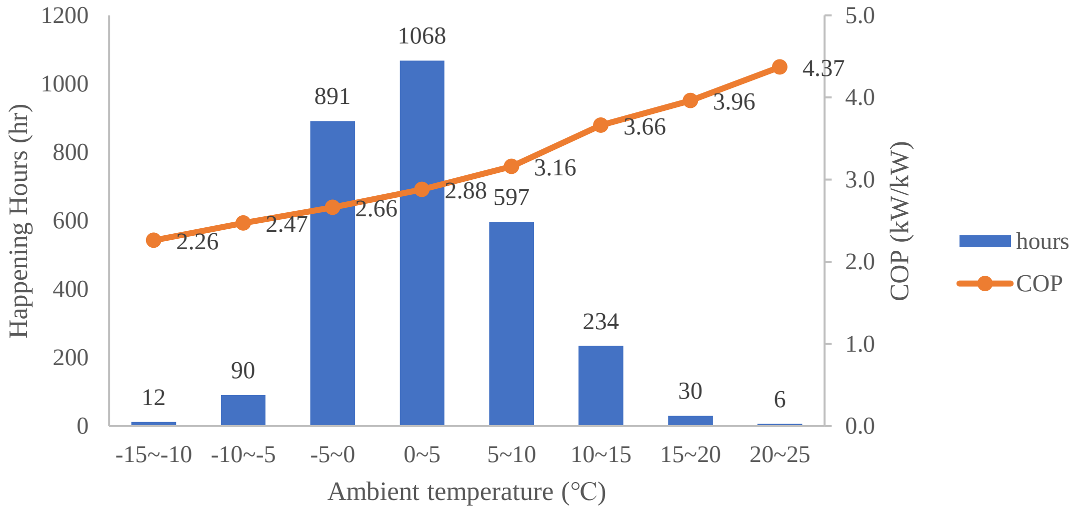


Fig.11. Climate bin data of Zhao County and COP of ASHP.

CO_2 emission comparing with coal boiler is show in Table 7, based on standard coal, ASHP can reduce around 38% CO_2 emission.

Table 7 CO_2 emission comparison.

	ASHP	Coal boiler
efficiency	293%	60%
CO_2 emission unit	0.997 kg/kWh	2.7 kg/kg
heating energy per unit	10548 kJ/kWh	17584 kJ/kg
CO_2 emission per kJ	0.095 g/kJ	0.154 g/kJ

The total electrical energy consumption in the heating season of 2019-2020 is 100.37 million kWh. The energy consumed by the water pumps is about 8% of the total one. Therefore, the ASHP unit's actual consumption of energy is 92.34million kWh, and the total heating energy produced by the ASHP units is 974002.32 million kJ. The reduction of the CO_2 is 57466.1 tons, and the standard coal reduction is 21522.9 tons.

5.4. Feedback on ASHP heating project

By on site interview, average indoor temperature can reach 20-22 ℃, no air polluted in Zhao County, residential people are satisfied with the heating project. Heat company also saves the cost by replacing coal boiler with ASHPs.

6. Conclusion

This paper presents a large air source heat pump project in Zhao County, which has the advantages of fast fault response, low maintenance cost, and significant energy savings. The main conclusions are as follows.

- The COP of the air source heat pump stations selected was above 2.8. When the outdoor temperature was -15 ~ -10 ℃, the heat pump cop could still reach 2.26.
- The cost of gas boiler heating is more than twice that of air source heat pump heating.
- Based on standard coal, air source heat pump can reduce carbon dioxide emissions by about 38% compared with coal-fired boilers.

Acknowledgements

We gratefully acknowledge the valuable cooperation of heat company of Zhao County, and their history data plays an important role in the system design.