

Research Article

Analysis and Research on Energy-Saving Reconstruction of Building Heating System

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A building heating system had high energy consumption and did not meet the requirements of environmental protection, so it was needed to be reformed. After recalculating the heat load, it was found that the heat source, pipe network specification, and radiator area of the original heating system were oversized. After comparing with a gas-fired boiler, the heat source was transformed into the water source heat pump system. The water supply temperature of the water source heat pump was lower than that of the boiler. Generally, it seemed necessary to increase the radiator area. However, after calculation and verification, when the supply and return water temperature was 65/58°C, the system operated continuously and the original pipe network and radiator could still ensure the indoor temperature of 16°C. The total cost of transformation was 11.5 million Chinese Yuan. After analyzing the operation data of the new system, the water source heat pump system could save 82.6% energy compared with the original system and 29.6% cost compared with the central heating system. The transformation is successful, and the experience is worth popularizing.

1. Introduction

In recent years, with more stringent environmental policies, coal-fired boilers for heating are restricted. Many places have been actively promoting “coal to electricity” or “coal to gas” [1, 2]. For buildings outside the scope of central heating, the selection of heat source type needs to consider the factors of technology, environmental protection, energy conservation, and economy. This requires engineers to determine the form of heat source according to local conditions, not mechanically.

Many professionals have studied the heating transformation. Zhang [3] summarized the appropriate technologies and application characteristics of energy-saving renovation of public buildings in hot summer and cold winter zones. Wang et al. [4] took a university located in Jinan Shandong province as an example to investigate the performance of the energy-saving transformation system. He et al. [5] analyzed the problems from various aspects in Karamay Experimental High School, such as heat source, primary circuit, secondary circuit, indoor heating system, and building envelope

structure and put forward the corresponding solutions. After taking measures, the system reached the heating standard. After investigating the cold and heat source system of a middle school in cold area, Zhi-yong et al. [6] carried out energy-saving transformation of the original cold and heat source system from three aspects of load forecasting, transformation scheme design, and transformation benefit analysis. Li [7] used water source heat pump to heat the shaft, which reduced the operating cost by 1.1086 million Chinese Yuan per year.

The application of heat pump in different occasions had also been studied by many scholars. Wu et al. [8] studied the operation characteristics of a closed-loop surface river source heat pump. Li et al. [9] studied the application of seawater-source heat pump in aquaculture. Sun and Li [10, 11] used the technology of mine water source heat pump to supply the heating and cooling of industrial area, which had achieved remarkable economic benefits. Liu et al. [12–14] had studied the application of sewage source heat pump in heating.

In this paper, taking the heating system reconstruction of a waterworks as an example, this paper analyzes the process and thinking of determining the heat source according to the actual situation of the project and comprehensively considers various factors and analyzes the transformation effect.

2. Project Overview

A waterworks, located in Linfen City, Shanxi Province, China, was built in the 1980s with a water supply capacity of 2500 m³/h. All the water comes from underground. There are 2530 square meters of living buildings such as office building (three floors), 6544 square meters of production buildings such as various water treatment workshops (one floor), 3926 square meters of various water pools, with a total construction area of 13000 square meters, including 9970 square meters of heating construction area. There is no central heating pipe network near the plant area. The heat source was a coal-fired hot water boiler with a rated thermal power of 1400 kW, and the indoor radiator heating system was adopted. When the outdoor temperature was lower than 0°C, the boiler system started up and run in intermittent heating mode, and the heating lasted for 5 months every year. During the operation, the average indoor temperature was maintained at 16°C. The average annual consumption of coal was about 700 tons, and the average annual heating cost is 55.1 Chinese Yuan per square meter. The local central heating cost standard is only 23.2 Chinese Yuan per square meter. Thus, the operation cost of the system was very high and the energy waste was serious. At the same time, the local environmental protection policy also began to limit the use of coal-fired boilers, so the energy-saving transformation of heating source was considered.

3. Determination of Heat Source Type

The heating load was recalculated according to the enclosure structure, as shown in Table 1. According to the calculation, the heating load is 648.55 kW, less than half of the original boiler heating power (1400 kW).

There was no central heating pipe network around the plant area, but there was a natural gas pipeline network. At the same time, the plant was rich in water resources, so gas-fired boilers or water source heat pumps were mainly considered as heat sources. According to the investigation, the local natural gas price was 3.2 Chinese Yuan per cubic meter. Gas cost was calculated as shown in Table 2. The cost of gas is 60.28 Chinese Yuan per square meter, even higher than the original coal cost (55.1 Chinese Yuan per square meter).

The water source of the waterworks is well water with a temperature of (17 ± 1)°C, which is suitable for the operation of water source heat pump units in winter. In addition, the waterworks purifies 60000 cubic meters of water every day and operates 24 hours, which can meet the requirements of water source heat pump units. Based on the above analysis, the feasibility of water source heat pump was mainly considered.

4. Determination of Water Source Heat Pump Heating Scheme

4.1. Problems and Analysis of Inconsistency of Supply and Return Water Temperature between Water Source Heat Pump System and Boiler System. According to the actual situation, the water supply temperature of the original boiler system is 80°C, and the temperature difference between supply and return water was 25°C. However, for water source heat pump, the highest temperature of heating water is 65°C, and the temperature difference between supply and return water is generally between 5°C and 15°C (obtained by investigating the manufacturers of heat pump units). Therefore, if the water source heat pump is used to replace the boiler, the water supply temperature will be reduced, and the water temperature difference between supply and return will be smaller. The decrease of water temperature will lead to the decrease of heat dissipation capacity of the radiator; to keep the heat dissipation constant, it seems necessary to increase the radiator area. At the same time, the smaller temperature difference means more flow.

4.1.1. Determination of Temperature Difference between Supply and Return Water of Heat Pump System. The greater the temperature difference of the heat pump system, the smaller the system resistance loss, the more likely to use the old pipe network. According to the excavation investigation, the main pipe of outdoor heating pipe network in the plant is made of DN 125 welded steel pipe. The specific friction is calculated by taking the temperature difference between supply and return water at 5°C, 7°C, and 10°C, and the calculation results are shown in Table 3. When the temperature difference is 7°C and 10°C, the flow meets the requirements of economic specific friction resistance range (30–100 Pa/m [19]).

4.1.2. The Influence of the Decrease of Water Temperature on the Number of Radiators. Two-pipe heating system was used in most buildings of this project. For the convenience of analysis, the inlet and outlet water temperatures of radiator are equal to the temperature of water supply and return of heat source in the following analysis.

According to formulas (1)–(3) [18], the decrease of Inlet water temperature of radiator will lead to the decrease of heat dissipation of single radiator. In order to keep the indoor heat supply constant, it is necessary to increase the number of radiators. From this point of view, it is necessary to reform the indoor heating system after using heat pump:

$$t_{pj} = \frac{t_{sg} + t_{sh}}{2}, \quad (1)$$

$$q = 0.657(t_{pj} - t_n)^{1.306}, \quad (2)$$

$$n = \frac{Q}{q}, \quad (3)$$

TABLE 1: Head load of buildings.

Building	Floorage (m ²)	Heat load (kW)	Heating index (W/m ²)
Office building	2700	183.6	68
Advanced water treatment workshop	2300	138	60
Chemical feed room	1300	88.4	68
Other workshops	3670	238.55	65
Total	9970	648.55	65.1

TABLE 2: Calculation of gas cost.

Parameter name	Parameter value	Unit
Days of heating period	150	d
Heating load	648.55	kW
Inside air calculating temperature for heating	18 [15]	°C
Outdoor mean air temperature during heating period	1.1 [15]	°C
Outdoor air temperature for heating calculating	-6.6 [15]	°C
Annual consumption of heat	6525.99 [16]	GJ
Calorific value of natural gas	38.6 [17]	MJ/m ³
Thermal efficiency of boiler	0.9	
Natural gas consumption	187790.09	m ³
Overall floorage	9970	m ²
Gas fee	60.28	Chinese Yuan/m ²

TABLE 3: Calculation of specific friction under different temperature difference.

Heat load (kW)	Supply water temperature (°C)	Return water temperature (°C)	Temperature difference between supply and return water (°C)	Flow (m ³ /h)	Pipe diameter (mm)	Specific frictional resistance (Pa/m)
648.55	65	60	5	111.5	150	218.81 [18]
		58	7	79.5		110.3 [18]
		55	10	55.7		55.08 [18]

where n is the number of radiators per group, slice/group; Q is the heat release of radiator, W/group; q is the heat release of each radiator, W/piece; t_{pj} is the average water temperature in radiator, °C; t_n is the indoor design temperature for heating, °C; t_{sg} is the inlet water temperature of radiator, °C; and t_{sh} is the outlet water temperature of radiator, °C.

However, by investigating the number of radiators and calculating their heating capacity, as shown in Table 4, it can be found that the number of radiators exceeds the actual demand under the original heating conditions ($Q_s > D_{HL}$). At the same time, the heating capacity under the condition of heat pump is calculated. As shown in Table 4, when the supply and return water temperature is 65/58°C, the indoor temperature is 16°C, which can meet the standard of the original system.

For the heat pump system, on the one hand, in order to use the original radiator, the temperature of supply and return water should be increased; on the other hand, in order to use the original pipe network, the temperature difference of supply and return water should be increased. If the water supply temperature of the heat pump unit is higher than 65°C, its working efficiency will decrease significantly. When the water supply temperature is constant and the water temperature difference between supply and return is enlarged, the flow resistance loss of the pipe network will be reduced, but the heat dissipation capacity of the original radiator will also be reduced. When the supply and return

water temperature is 65/58°C, the original pipe network and radiator can be used to meet the requirements, and the operation energy consumption can be reduced to the greatest extent.

4.2. Measures to Prevent Heat Pump System from Polluting Water. Using water source heat pump unit, the well water should be directly connected to the evaporator in the unit. In the evaporator, the refrigerant and water exchange heat through the copper tube, which will not pollute the water under normal conditions. However, if there is a rupture of the copper tube, resulting in the leakage of refrigerant, it will cause pollution. In order to prevent this situation, water-water heat exchanger can be added to completely isolate water source system and refrigerant system. In order to prevent the pollution caused by the pipeline system, high-density polyethylene is selected as the pipe material, and copper or stainless steel material is selected for the valve.

4.3. Heat Source Reconstruction Scheme of the Waterworks. There are not only static water sources such as pools but also flowing water sources such as various pipelines. The initial investment and operation cost of intake pump can be saved by using the water in the pipeline. The use of the flowing water source can save the cost by not using intake pump. Through field investigation and analysis, it is determined

TABLE 4: The number of radiators in each building and its heating capacity.

Building	Number of radiators per square meter, n (slice/m ²)	Heat release of each radiator when the supply and return water temperatures are 65/58°C and the indoor temperature is 16°C, q_2 (W/piece)	The heat supply per square meter when the supply and return water temperatures are 65/58°C and the indoor temperature is 16°C ($Q_{s2} = q_2 * n$, (W/m ²))
Office building	0.69	63.48	66.7
Advanced water treatment workshop	0.63	57.96	60.9
Chemical feed room	0.71	65.32	68.6
Other workshops	0.63	57.96	60.9

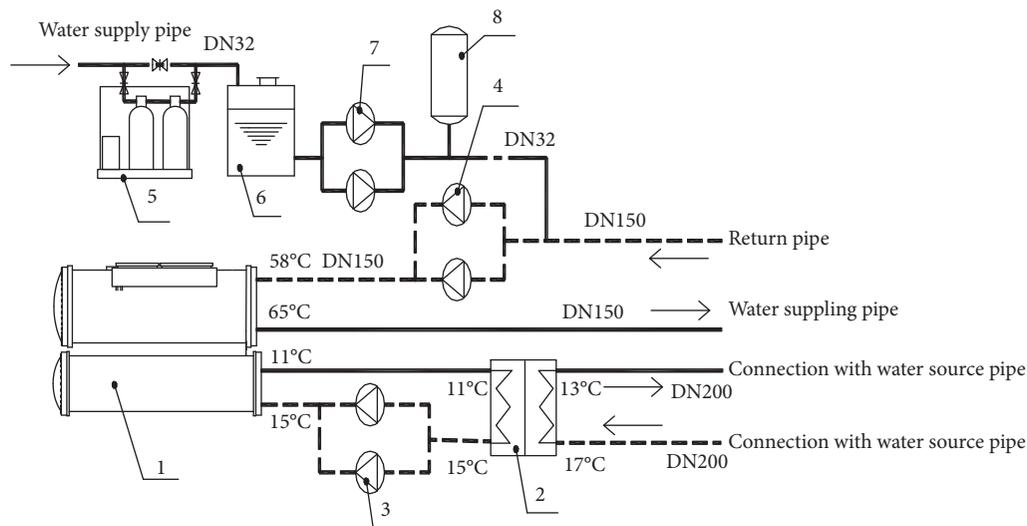


FIGURE 1: Flow chart of water source heat pump system.

that part of the water from the underground pump house to the advanced water treatment workshop is led out from the water supply pipeline as the water source of the heat pump unit. Based on the above analysis, the process flow of the water source heat pump system was determined, as shown in Figure 1, and the main equipment parameters are shown in Table 5. The system can automatically adjust the water supply temperature according to the outdoor air temperature, which can not only save energy but also save labor management costs.

5. Economic Analysis of Water Source Heat Pump System

5.1. Initial Investment and Operation Cost of Water Source Heat Pump System. The reconstruction cost of the system included the equipment, pipeline, and electrical system of the heat pump room, as well as the water intake pipeline, with a total cost of 1.15 million Chinese Yuan.

The water source heat pump system was completed in October 2014 and put into use in November of the same year. It runs 24 hours and lasts for 5 months in each heating season (the central heating time is 4 months). So far, the water source heat pump system has been operating well. The indoor temperature has been kept in the range of 16–18°C.

After the transformation, the power consumption of the system is shown in Table 6.

5.2. Energy-Saving Analysis Compared with the Original System. Before reconstruction, the annual energy consumption of heating system is 2154000 kW h (as shown in Table 7), at present, the annual power consumption of heat pump heating system is 374126.7 kW h (as shown in Table 6). The energy consumption of the heat pump system is only 17.4% of that of the original boiler system, and the energy-saving rate reaches 82.6%.

5.3. Economic Analysis Compared with Central Heating. The heat pump system runs five months a year, but the local central heating system runs four months a year. In order to compare the operation costs of the two heating modes, half of the energy in the first month and the last month of the heat pump system operation period is converted, as shown in Table 8. Obviously, the converted system operation cost is only 16.35 Chinese Yuan/(m²•year), but the cost of central heating in this city is 23.2 Chinese Yuan/(m²•year), and the operation cost of the heat pump system is only 70.4% of the central heating cost. All in all, the heat source transformation is very successful, saving energy and money.

TABLE 5: Parameters of main equipment.

Equipment number	Equipment name	Equipment parameters
1	Water-source heat pumps	The heating capacity under design condition is 702 kW
2	Plate heat exchanger	The heat transfer capacity under design condition is 550 kW
3	Circulating water pump	The flow rate is 120 m ³ /h, the lift is 8 m H ₂ O
4	Circulating water pump	The flow rate is 73 m ³ /h, the lift is 32 m H ₂ O
5	Water softener	The water treatment capacity is 1.0 m ³ /h
6	Soft water tank	The volume is 1.0 m ³
7	Make-up water pump	The flow rate is 1.0 m ³ /h, the lift is 22 m H ₂ O
8	Pressure tank	The regulating volume is 0.2 m ³

TABLE 6: Power consumption statistics of the system after transformation.

Month	Power consumption (kW·h)				Subtotal	Average value
	The first year	The second year	The third year			
November	54560	39980	56340		150880	50293.33
December	93860	83520	89540		266920	88973.33
January	93480	107160	133100		333740	111246.67
February	66460	86800	80200		233460	77820.00
March	34700	56480	46200		137380	45793.33
Total	343060	373940	405380		1122380	374126.67

TABLE 7: Energy consumption of original system.

Name	Number/power	Coal consumption rate of power supply/operation time of circulating pump	Equivalent electric energy consumption
Coal	700 t	333 g/kW·h [20]	2100000 kW·h
Circulating pump	20 kW	2700 hours	54000 kW·h
Equivalent power consumption of original system			2154000 kW·h

TABLE 8: Converted operating cost of heat pump system.

Month	Actual power consumption in three years (kW·h)	Converted power consumption in three years (kW·h)	Unit price of electricity (Chinese Yuan/kW·h)	Average annual converted electric charge (Chinese Yuan)	Floorage (m ²)	Average annual electricity charge per unit area (Chinese Yuan/(m ² ·year))
November	150880	75440		37720		1.26
December	266920	266920		133460		4.46
January	333740	333740		166870		5.58
February	233460	233460	0.5	116730	9970	3.90
March	137380	68690		34345		1.15
Total	1122380	978250		489125		16.35

6. Conclusion

- (1) For projects with abundant water resources, such as waterworks, it is a relatively economic scheme to use water source heat pump in winter. The operation cost of water source heat pump system is only 70.4% of the cost of central heating in local cities.
- (2) In some heating transformation projects of heat pump replacing boiler, although the temperature of supply and return water decreases, it is not necessary to increase the number of radiators, which needs to be calculated and verified according to the actual situation. This is caused by the excessive number of radiators in the original system.

- (3) For waterworks, when water source heat pump unit is used as heating source, it is necessary to take measures to prevent water pollution, such as setting heat exchanger.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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