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EXPERIMENTAL STUDY AND APPLICATION ANALYSIS ON GROUND-WATER SOURCE HEAT PUMP IN NORTH CHINA

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ABSTRACT

To describe the economical performance and operational characteristic of ground-water source heat pump system (GWSHPS) in North China, GWSHPS was compared with traditional central air-conditioning system (TCACS) for their total investments based upon a GWSHPS demonstration project in Beijing (88000 m^2 covered area, 4572 kW heat exchange amount). At the same period, an experimental system of GWSHPS in Hebei was investigated with its operational data such as coefficient of performance (COP). The results of the demonstration project showed that the total investment for GWSHPS was 15.2% lower than TCACS, while annual operating cost for GWSHPS was 42.2% lower than TCACS. The test data of the system in Hebei showed that heating coefficient of performance of the heat pump and primary energy ratio (PER) were raised while heating water temperature was decreased. The entering water temperature to the unit ranged from 13.1℃ to 17.4℃, with an average value of 15 ℃, the heating water temperature varied from 40℃ to 50℃, with the standard work condition of 45℃. The COP_{HP} was about 4.12 at the minimum of heating water temperature, while it was about 3.47 at the maximum of heating water temperature and fluctuated between these values in other temperature. The results of the present work implies that GWSHPS is favorable for North China. However, buildings in North China have high heat load in winter, consequently, GWSHPS designed upon heat load will cause a waste in summer, thus, the solar-assisted ground-water source heat pump system (SAGWSHPS) which combines heat pump with solar water heater can be suggested as the best solution in North China.

1. INTRODUCTION

Essentially, Conventional energy is not sufficient in China due to the excessive population and energy conservation is one of the most important subjects as well as environmental protection. To improve the standard of living, space heating in winter and hot water production is required in many areas, especially north China, where fossil fuel is used. Thus high primary energy consumption and many forms of air pollution will be unavoidable. This situation has stimulated the development, extension and application of direct utilization of geothermal energy such as ground-water source heat pump system (GWSHPS). In recent years, numerous studies have been conducted to describe the rationale, development and status of geothermal heat pumps (e.g. Gerald, 1997; Miklos, 2003; Kamil & Abdullah, 2004; Burkhard et al., 2003). However, very little is known about their economic performance. In fact, the use of geothermal heat pumps is considerably decided by two influencing factors: investment costs and operating costs. In this regard, investigations conducted on economic performance are getting more and more importance. The expenses of investing and operating TCACS and GWSHPS for a demonstration project both in heating and cooling periods was calculated in this research and the results proved that GWSHPS could achieve better economic performance, afterwards, the operational data of an experimental system of GWSHPS in Hebei was also examined. Furthermore, this study suggested SAGWSHPS should be a good selection in North China.

2. ECONOMIC EVALUATION

An economic comparison was performed between TCACS and GWSHPS of a demonstration project located in Beijing (latitude 39°54′ north, altitude 44m, in the north of China), a front view of the project is given in Fig.1.

Fig. 1. Front view of the project

There are 88000m^2 of total floor area, about 70000 m^2 of which has air-conditioning, the entire cooling load is designed as 4572 kW, meanwhile, 501 ground-water source heat pump units are used. Ground water comes from four wells, 160 m depth and 500 mm diameter, the two wells are used for withdrawing and the other two are used for injection. The authors calculate the expenses (Table 1) of investing and operating TCACS and GWSHPS.

Table 1 Economic comparison

System		GWSHPS		TCACS	
Unit		￥/m^2	Ten-thousand ￥	￥/m^2	Ten-thousand ￥
investment	Equipment cost	224	1572	219	1533.9
	Engineering cost	136	952	147	1029
Total investment		360	2524	366	2562.9
Operating cost (annual)	heating	12.9	150.1	30	264
	cooling	8.5	74.8	14.2	125
Occupied floor cost		2500	37.5	2500	87.5

As shown in Table 1, the cost of 25629000￥of total investment for TCACS is limited to 2524000￥for GWSHPS, at the same time, the annual operating cost is reduced from 3890000￥for TCACS to only 2249000￥ for GWSHPS, moreover, 500000￥ could be saved of the occupied floor cost if GWSHPS is adopted. A schematic of the two systems is shown in Fig.2.

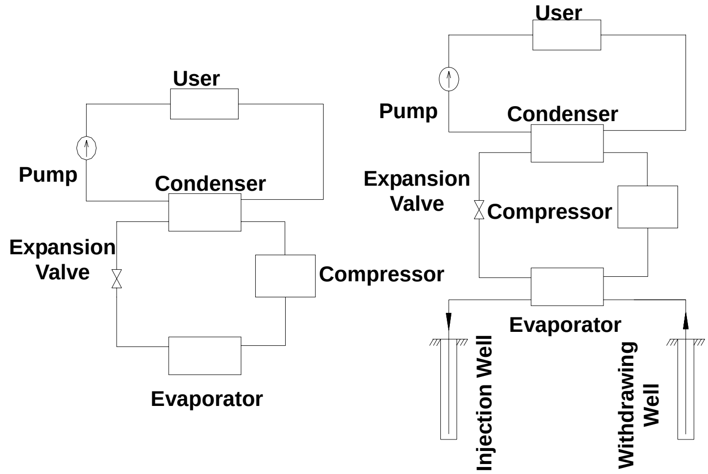

Fig.2. Schematic of the two systems

3. EXPERIMENTS

In this study, an experimental system located in Hebei (latitude 38°02′ north, altitude 77.9m, in the north of China) is considered to analyze the operating performance of GWSHPS.

3-1. Geologic Exploration

The confirmation of water source is a critical factor for GWSHPS. After consulting relative policies and getting a permission from the Office of Water Source, a hydrogeology survey was carried out on the designated spot with two 45m-boreholes drilled, the distance between the two holes was about 45m. Based on the obtained geologic information, this area was a region of outflow for phreatic water and the stratum consisted of nine layers: ① filling soil, ② silt, ③ slush, ④ sand, ⑤ clay soil, ⑥ breccia, ⑦ silty clay, ⑧ silty clay (sand mulling), ⑨ decomposed mica slate. The fourth layer was the main water-bearing zone as well as the eighth layer which contained confined groundwater. The underground water level was about 5-6 m and the water volume supplied by the well was 20-24 m^3/h.

3-2. System Design

This system mainly consists of three separate circuits: ① ground water circuit (water is pumped out the well, passes through the heat pump heat exchanger and then discharges back into the source) ② the refrigerant circuit (or a reversible vapor compression cycle) and ③ fan-coil circuit for users.

3-2-1. Withdrawing well and injection well

According to the technological requirements of this GWSHPS, the flux of underground water circuit should be greater than 40 m^3/h, thus two wells were used for withdrawing with 45 m depth and 800 mm diameter. The well-water temperature was 17 ℃ in summer and 14 ℃ in winter. In order to keep in balance the underground water system, the other two wells were used for injection with 45 m depth and 1200 mm diameter. The distance between each two wells was about 30 m.

3-2-2. Heat pump

The heat pumps were made by YANTAI MOON GROUP Co.Ltd, two modular cold water units of DZW-110 type were adopted and their rated power was 17 kW.

3-3. Construction and Operation

The construction of this project lasted from January 5th to February 9th in 2004 after the engineering design was accomplished. The system's commissioning was executed in February 26th while external environmental temperature was 2 ℃ and ground water temperature was 12 ℃.

4. RESULTS AND DISCUSSIONS

In order to evaluate operating performance, the system was monitored under the conditions of various heating water temperature during heating periods.

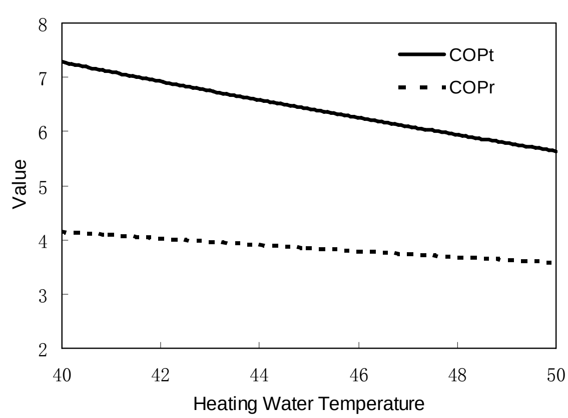

Fig.3. COP of the GWSHPS

Fig.3 shows theoretical COP (COPt) and experimental COP (COPr). COP is the ratio between heat rate at evaporator and compression work, it can be calculated from:

$$COP=QE/WC$$

Where:

QE – heat rate at evaporator, kW

WC – compression work, kW

Commonly, COP of GWSHPS was 30% higher than that of TCACS (Sun et al., 2002). In our study, the entering water temperature to the unit ranged from 13.1℃ to 17.4℃, with an average value of 15℃, meanwhile, the heating water temperature varied from 40℃ to 50℃. Also, it can be seen that COP_r was about 4.12 at the minimum of heating water temperature, while it was about 3.47 at the maximum of heating water temperature and fluctuated between these values in other temperature. Both COPt and COPr were decreased while heating water temperature was increased, moreover, COPt decreased sharper than COPr. Under the standard work condition (heating water temperature was 45 ℃ and ground water inlet temperature was 15 ℃), COPt of this system was 6.31 while COPr was 3.85.

Fig. 4 shows Primary Energy Ratio (PER) which reflects energy utilization degree and Electric Energy Ratio (ELER) of this system.

It can be seen, from Fig. 4, that PER ranged from 1.44 to 1.19 in this heating water temperature level while ELER ranged from 0.38 to 0.64. It is obvious that PER would increase with the drop of heating water temperature, as a result, operating cost would be decreased. Contrarily, ELER would be reduced if heating water temperature rose. Consequently, heat capacity would be improved and operating cost would be increased.

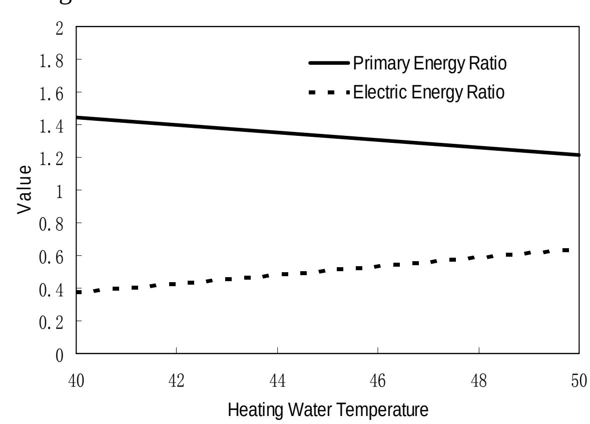

Fig.4. PER and ELER of the GWSHPS

As shown in these two figures, performance parameters mentioned above would be greatly changed in different work conditions.

Combined with the acquired data, a review of the literature suggests that PER of this GWSHPS is much higher than other heating systems such as electric boiler and gas boiler. In this regard, GWSHPS can be expected to obtain the target of energy conservation as a mature technology. However, since most areas in North China have very low environmental temperature in winter, buildings in these fields will have high heat loads correspondingly, thus heat load is mainly considered during system design. If GWSHPS is adopted as a single cooling and heating resource, the capacity of unit will be relatively excessive in summer and energy will be wasted. Furthermore, since heat taken out from ground in winter is more than heat injected to ground in summer in these regions, ground temperature will be decreased in a long running, therefore, GWSHPS will also get a low COP and the system can't meet design requirements. To solve these problems, solar-assisted ground-water source heat pump system (SAGWSHPS) is proposed to be applied. First of all, systems can be designed in summer operating mode, secondly, SAGWSHPS can increase unit evaporation temperature during heating period so that power consumption of compressor is decreased as well as operating costs, meanwhile, solar collectors can be auxiliary radiating equipments while operating in summer nights and heat rejection to ground is reduced sequentially, then ground temperature will be relatively stable and units can operate in high efficiency. Finally, a higher evaporation temperature in winter can increase outlet air temperature of fan coil, hence thermal comfort can be achieved.

5. CONCLUSIONS

In summary, from the results obtained up till now, the following can be stated:

1. Compared with TCACS, GWSHPS can acquire better economic performance such as total investments and operating costs, besides this, occupied floor costs ars also reduced due to national policies. However, the cost savings between GWSHPS and TCACS remain to be further studied.
2. Experimental results show that the COPr and COPt for the GWSHPS are obtained to be 3.85 and 6.31, respectively. COPt is much bigger than COPr because some energy loss was ignored in the course of calculation. As a result, COPt should only be a reference in the selection and design of GWSHPS.
3. In this system, PER ranged from 1.44 to 1.19 with an average value of 1.34, ELER ranged from 0.38 to 0.64 with an average value of 0.52. These results support the idea that GWSHPS can save energy compared with other heating systems such as electric boiler and gas boiler.
4. The use of SAGWSHPS can be suggested as best solution in North China. It can greatly improve the thermal performance of the system and avoid the weakness of GWSHPS. But, it also has some problems such as low solar energy density and the rate of soil heat flow, and so on. Thereby, the use and design of SAGWSHPS should be considered synthetically.

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