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A Case Study of Ground Source Heat Pump System in China

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ABSTRACT

A case study of a ground source coupled heat pump and air conditioning system in China is introduced in the paper. Two types of U shaped Ground Coupled Heat Exchangers (GCHE) were adopted. One is the conventional closed loop borehole heat exchanger, and the other is the heat exchanger buried in the foundation pile. The floor area to be heated in winter or cooled in the summer is 3715 m^2, with a heating load of 148kW and a cooling load of 320kW. The system has been operated since 2003 and data for one year are summarized and analyzed. These data include the inlet and outlet temperatures of the GCHE and the surrounding soil temperature. The heating and cooling performances of the system are also evaluated.

1. INTRODUCTION

Closed loop ground coupled heat exchangers have been used increasingly in heating and air-conditioning systems in the world (Bose, 1993). These systems have the least disturbance both to the ground water system and to the surrounding environment. However, since these systems need a larger surface area and cost a higher capital investment compared with ordinary systems, they are still uncommon in a developing country such as China. Some heat transfer characteristics of the ground coupled heat exchanger had been investigated previously in a laboratory scale (Dai, 1995 and Zhao et al., 2000). In this paper, a ground source heat pump and air-conditioning system (GSHP) is introduced. The heating and cooling performances, and the technical and economic potentials of using these systems are analyzed.

The ground source heat pump and air-conditioning system was for heating or cooling an office building of a local government in Meijiang Eco-region, Hexi district, Tianjin. The construction project was designed as a demonstration model in order to evaluate the competitiveness and the application potential compared to the others methods of heating and cooling. The schematic diagram of the system is as shown in Fig. 1. It is composed of three parts: the GCHE system under the surface, the heat pump/air-conditioning system using the screw compressor above the surface and the terminal heat radiators inside the buildings.

The total floor area is 3715 m^2, The designed heating load in winter is 148 kW, while in summer the cooling load is 320 kW. We assumed that the atmosphere-influenced depth was about 20 meters; the ambient temperature has an average of 13.5ºC in the whole year in Tianjin. The formation temperature has a slightly increasing temperature with depth; the proportional coefficient is about 1.5ºC per hundred meters. According to these data, the U shaped borehole heat exchanger and the U shaped pipe buried in the foundation piles were constructed. A total of, 61 foundation piles have a U shaped loop inside, and their depths are 20 meters. The borehole and the pile spacing are about 5 meters. The depth of the convectional borehole heat exchanger is 90 meters, and 21 boreholes are used. All these pipes are made of high-density polyethylene, and have a diameter of 32 mm.

A data acquisition system was designed, in which all of the measured data were collected and processed through a personal computer. The collected data are the formation temperatures surrounding a borehole (40 points), the water flow rates through the loops (4 locations) and the consumed electric power (4 pumps). The positions of the measuring instruments are shown in Fig. 2.

2. EXPERIMENTAL RESULTS OF GROUND SOURCE HEAT PUMP (GSHP)

The GSHP system was completed in Mar 2003, and a trial run was carried out from Mar 11 to Mar 23, 2003. During this winter period the system was operated as a heat pump. The system was switched to the air-conditioning function in the summer period from July 10 to Sep. 9, 2003. The running period of the system was varied from 2 to 12 hrs in a day. Since Nov. 17, it came into a winter period again and the system was operated from Monday to Friday, but shut down at weekends. The running mode was such that the system was operated from 8am to 5pm, and was turned off at night.

2.1 Results in the Summer Season

2.1.1 Ambient Temperature, Indoor Temperature, Inlet and Outlet Temperatures of GCHE, Supply and Return Temperatures of Cooling Water

The experimental period covered from July 10 to Sep. 9, 2003, a total of 61 days. The indoor and ambient temperature during the summer season are shown in Fig. 3. The ambient temperature had a large variation from 27.7ºC to 41.5ºC while the room temperature was controlled from 23ºC to 26.2ºC, which indicates that the designed system met the real cooling demand.

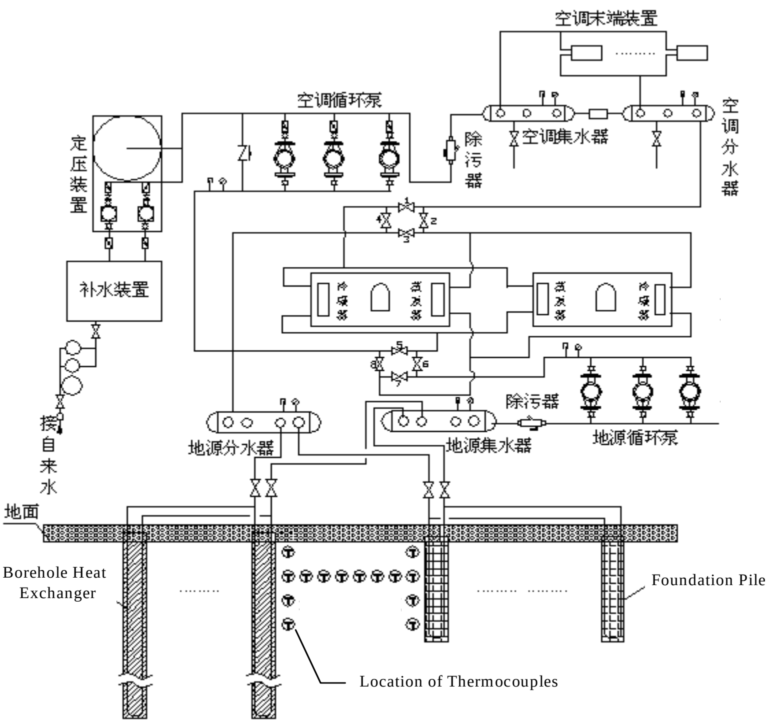

Figure 1: The schematic setup of ground source heat pump and air-conditioning system (two types of U shaped heat exchanger: borehole heat exchangers and that in foundation piles).

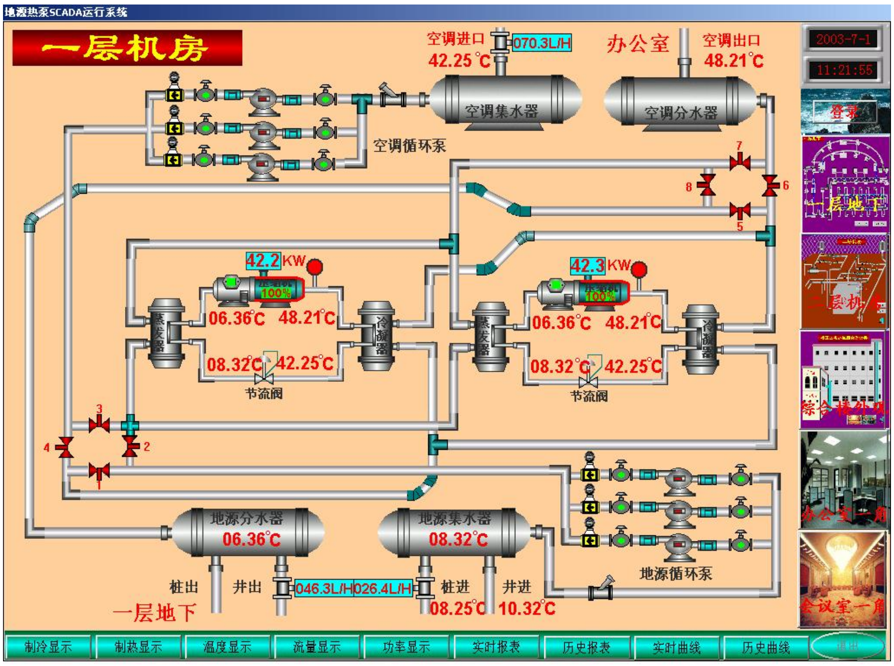

Figure 2: The computer monitoring and control interface of ground source heat pump and air-conditioning system.

The flow rate of circulating water through the rooms was 85 ton/h. The flow rate through the borehole heat exchanger and the U shaped pipes inside the foundation piles was 42 ton/h and 23 ton/h, respectively. The flow rates through both branches were not intentionally adjusted according to their total lengths. According to the experimental data, the outlet temperature of the borehole heat exchangers varied from 23.0ºC to 35.1ºC, an average of 29.7ºC,while the inlet temperature was from 24.6ºC to 38.7ºC, an average of 32.5 ºC. This indicates that in summer the temperature of cooling water out of a borehole heat exchanger could be relatively lower than that of normal air-cooling system or the system with a cooling tower. As a result, the GSHP could be operated with a higher coefficient of performance. The temperature of the supply cooling water was from 6.2ºC to 11.6ºC, and the average was 8.0ºC. The temperature of return water was from 7.2ºC to 13.8ºC, and the average was 9.3ºC. The temperature of return water was still below the ambient temperature that meets the requirements of the air-cooling system.

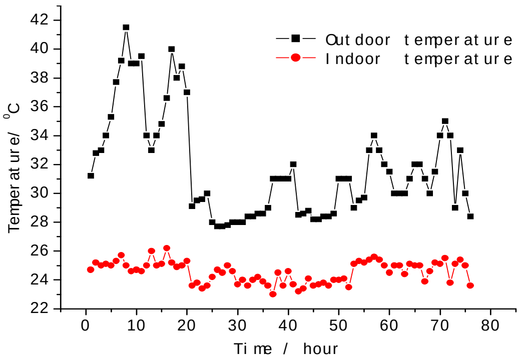

Figure 3: The ambient and indoor temperature in three consecutive days in the summer.

2.1.2 The Cooling Load, Heat Transferred Trough GCHE, Consumed Power and COPc in Summer

According to the measured data in our experiments the maximum cooling capacity could be up to 282 kW, the average was 130 kW; the maximum heat transferred to the ground was 403 kW, with 209kW on average. The COP of the system was in a range of 1.8 to 4.6, and the average was 2.7.

2.1.3 The Variation of Soil Temperature

In our experiments, the soil temperatures surrounding the GCHE for both types were also monitored during operation. The locations of the thermocouples for measuring the soil temperature are shown in Fig. 1. At the level of 8 meters down from the surface, the soil temperature in the radial direction was measured as shown in Fig. 4. In order to compare the heat transfer characteristics of U shaped loop inside the foundation pile with that of borehole heat exchanger, the temperature at a distance of 0.5m from a GCHE in the foundation pile and the temperature at a same distance from a borehole heat exchanger were measured. The following points could be noticed in Fig.4.

(1) The soil temperature at 0.5m from a borehole heat exchanger had a higher temperature than that at a same distance from the foundation pile. In our experiments, the temperature difference was from 4.5°C to 20.9°C. The temperature around the foundation pile was lower than that around the borehole heat exchanger.

(2) The trend of increasing temperature from this point to the point a little further away (2 m from the foundation pile) was shown during operation. This indicates that the thermal influence diameter for this case was more than 2 meters. The temperature at this point was increased by 2°C or from 14.5°C to 16.5°C.

(3) The temperature at a point 0.5 m from the borehole heat exchanger was the highest indicating the influence by the borehole heat exchanger. However, this was not apparent at the point a little further (1.5 m), and no influence could be seen at all beyond a distance of 2.0 m. It can be concluded that the influence diameter for a borehole heat exchanger was about 1.5 meters.

As a matter of fact, one row of borehole heat exchangers was adjacent to the U shaped heat exchanger in foundation piles (see Fig. 1). The heat extracted from the borehole heat exchanger and the adjacent foundation pile might be different, since the flow rates through the two type heat exchangers were different. The backfilling materials were also different for the two cases. The backfilling materials for the foundation piles were mainly concrete having a relatively larger thermal conductivity than that of sandy soil for the case of borehole heat exchanger.

2.2 Experimental Results in Winter Season

The analysis given below was based on the data collected from Nov. 2003 to Mar. 15, 2004.

2.2.1 The Supply and Return Temperatures of Hot Water, The Inlet and Outlet Temperatures of water through GCHE

The maximum supply temperature of hot water from the heat pump was 52.3°C, the average was 46°C. The the flowrate of load side circulating water was 72 ton/h, the water flowrate through the U shaped borehole heat exchanger was kept at 42 ton/h, and through the U shaped heat exchanger in the foundation pile 23 ton/h.

The GCHE outlet temperature was up to 51°C, the average was 44°C. The inlet temperature of the GCHE was about from 10.5°C to 15.5°C, having an average of 12.1°C, while the outlet temperature was from 11.7°C to 16.4°C having an average of 13.1°C. The water temperature from the GCHE was obviously higher than that from an air source, indicating that GSHP should have a larger COP for heating and better performance in saving energy.

2.2.2 The Supplied Heat in Winter, Extracted Heat from the Soil, Power Consumption and COPh

According to the measured data, the heat supplied by the system can be calculated. The maximum was 194 kW, the average was 126kW, the maximum heat gain from the soil was 152kW, and the average 72kW; the COPh for heating was from 2.1 to 5.6, an average of 3.5.

The data obtained in winter and summer show that the COPh or COPc for the whole system, which include the circulating pumps and the terminal radiators, were lower than those of a conventional air-sourced heat pump only approximately a third. Therefore, the heating/cooling capacity still had the potential to be improved by optimizing the fluid flow rates in the system in order to cut down the power consumption.

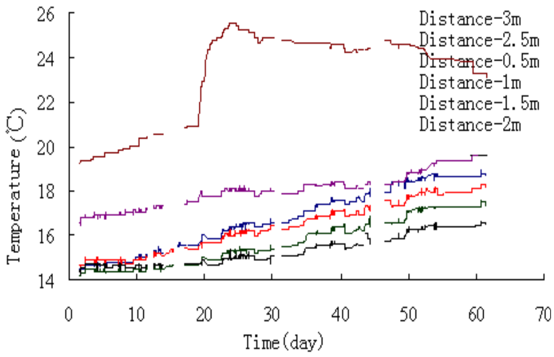

Figure 4: The time recording of soil temperature at various distances from a U shaped heat exchanger in the foundation pile (from July. 10, 2003).

2.2.3 The Variation of Soil Temperature

As mentioned in the previous section, the soil temperature was measured at the level of 8 meters down from the ground surface. The heating duty was started on Nov. 17, 2003. It is as shown in Fig. 5 that the heat transfer performance for the U shaped heat exchanger inside the foundation pile was better than that of the conventional borehole heat exchanger due to the thermal conductivity difference of the backfilling materials surrounding the U shaped pipes.

2.3 The Variation of Soil Temperature and the Heat Balance Analysis in a Whole Year

From Mar. 11, 2003 to Mar. 15, 2004, the heat pump/air conditioning system covered a whole season including a heating season in the winter and the cooling season in the summer. In the winter, the soil temperature surrounding the GCHE is decreased owing to the extraction heat from the soil. Conversely, the soil temperature should increase in the summer due to the heat transferred from the building. The process of heating the soil in summer can also be regarded as heat storage for later use in the winter, and vice versa. The soil temperature varied over a whole year that could be significantly different from the original one at the very beginning.

2.3.1 The Variation of Soil Temperature in a Year

Figures 5 and 6 show the soil temperatures at various locations from the GCHE. It can be seen that the soil temperature during the second heating season was increased by 2-4°C compared with that of the first season, but the increments varied with the location.

2.3.2 The Variation of Inlet and Outlet Temperature of GCHE

The measured inlet and outlet temperatures of the GCHE for the period from Mar. 11, 2003 to Mar. 26, 2004 are summarized and listed in Table 1. These data include the variation range and the average of outlet and inlet temperatures of GCHE over two continuous heating seasons.

Table 1. Inlet and Outlet Temperature of GSHE

	Inlet Temp.		Outlet Temp.	
Running period	Range °C	Average °C	Range °C	Average °C
Mar.11-26, 2003	4.1~11.3	7.6	6.0~11.4	8.4
Nov. 17,2003-Mar. 15, 2004	10.5~15.5	12.1	11.7~16.4	13.1
Increment		4.5		4.7

It is as shown in Table 1 that the inlet and outlet temperatures of the GCHE for the second heating season got higher than those of the first heating season. The average inlet temperature increased by about 4.5°C, and the outlet temperature by about 4.7°C. This was because the formation soil temperature became higher for the second season due to heat storage effect in the summer between the two winter seasons.

2.3.3 The Heat Balance Analysis of the Soil

As pointed out in the previous section, the soil supplied heat in the winter season and its temperature decreased, however, in the summer, the soil absorbed heat and its temperature increased. Generally, the cooling load in the summer is about twice of the heating load in the winter in Tianjin, China. For this case, the designed heating load was 148 kW, and the cooling load 320 kW, i.e. the cooling load was about 2.16 times the heating load. In practice, the heat emitted to the soil in the summer was about 400 kW and heat extracted from the soil in the winter was 103 kW with the former being about 3.88 times the latter. This could result in a soil temperature increasing across the whole year. The time accumulated emitted heat to the soil in summer was 2.98×10^5 MJ, while in winter the extracted heat from the soil was 2.03×10^5 MJ. The net gain of heat for the soil leads to an increasing formation temperature. The effect due to the unbalance of total heat to and from the soil seems to be positive in the winter but negative in the summer. Another possible reason for the soil temperature increasing during the whole year was the closed spacing between boreholes and piles. The proper spacing between boreholes or piles can only be determined on the considerations of available surface area; the economic depths of U shaped heat exchanger; the heating or cooling load; and surrounding formation properties. The whole system needs a long term monitoring regarding the actual effect in this case.

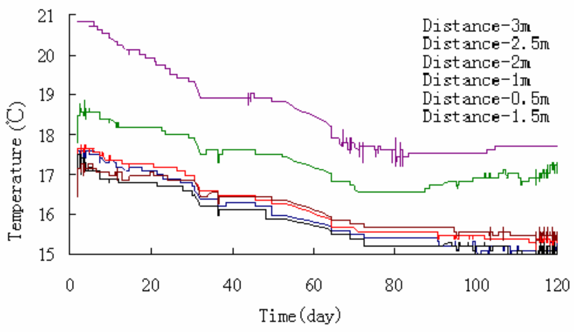

Figure 5: The time recording of soil temperature at various distances from a U shaped heat exchanger in the foundation pile (from Nov. 17, 2003).

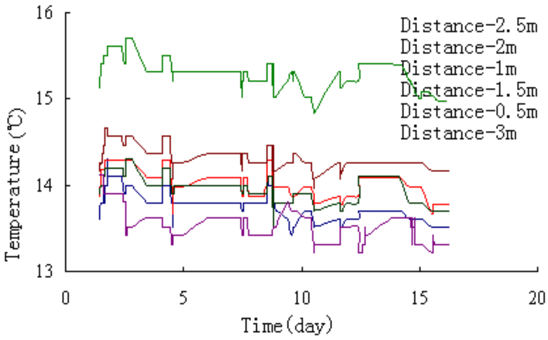

Figure 6: The time recording of soil temperature at various distances from a borehole heat exchanger (from Nov. 3, 2003).

3. SUMMARY

The experience of one-year operation of the ground source heat pump/air-conditioning system in Tianjin shows that this is a reliable and clean technique in district heating and/or cooling. It has been proved that the U shaped heat exchanger both buried in the foundation pile or inside a borehole could realize the heat transfer with the ground soil back and forth. The ground source actually played a role of a large heat storage tank when the system was switched to a heating function after a cooling season of summer, and vice versa. This advantage could somehow compensate the drawback of high initial capital investment. Due to the unbalance of total heat discharge and recharge for the two different seasons, however, some special considerations should be given on the designed heating load and operation arrangement. This technology has great potential and competitive advantage for heating and cooling buildings in China.

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