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Geothermal Heat Pump Utilization in Beijing

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ABSTRACT

Beijing is a city with a population of 17 million. The needs for space heating and cooling are ever increasing, with the fast expansion of construction and improvement of living conditions. The government is paying great attention to adjusting the energy structure, promoting the use of renewable energy and energy saving. In the area of Beijing, there are very good conditions for the utilization of shallow geothermal resources. Firstly, it is hot in the summer and cold in the winter in Beijing, and the heating and cooling needs are equally great. Secondly, the sediment of the Quaternary System in the Beijing plain is suitable for installation of GHP systems, either open loop systems or closed loop systems. The first two GHP systems were put into operation in the summer of 2000. After that, the GHP utilization developed rapidly. There have been about 600 such systems and the service area has been around 13 million m^2 till the end of 2008. GHP systems are economically viable. In addition, the environmental effects of GHP systems are also remarkable. From 2000 to 2008, the total amount of energy saving through the use of GHP systems in Beijing is estimated as 3.23×10^{10}MJ, accounting for the heat of 1.84×10^6 tons of coal and 4.38×10^6 tons of CO_2 emission reduction.

1. INTRODUCTION

Energy and environment have become amongst the most prominent factors constraining the development. Beijing is a big city with a population of about 17 million. With its rapid development, the energy needs are ever increasing. The development also causes a lot of environmental problems, such as air pollution, water pollution etc. Therefore, more and more attention is being paid to renewable energy utilization, reduction of CO_2 emission, and environmental protection in Beijing. Under this circumstance, the utilization of geothermal heat pumps for cooling and heating in Beijing is of great significance.

It is hot in the summer and cold in the winter in Beijing, and both cooling and heating needs are rather heavy. GHP systems can meet the needs of cooling and heating using the same unit, and it is very suitable for areas with climate conditions similar to Beijing.

GHP utilization started in Beijing in 2000, with the first two such systems putting into use. In 2006, the municipal government issued a policy for encouraging GHP utilization by subsidizing GHP system construction. The subsidy will be calculated according to the floor area of the served buildings, and the quota is 30 and 50 Yuan/m^2 for open and closed loop systems respectively. This further stimulated the installation of GHP. At present, there have been about 600 GHP systems in use, and the service area has been more than 13 million m^2.

A GHP system consists of heat pump units, tail end and underground heat exchangers. Generally, in the designing of a GHP system, the first two parts are relatively easy. Because the geological conditions in situ may be uncertain or complicated, it has been widely agreed in the geothermal community that the heat exchanger are often the most critical part of a GHP system. There are generally two kinds of underground heat exchangers: open loop and closed loop. Open loop heat exchangers (also called groundwater source heat pumps) often consist of a group of wells for groundwater pumping and reinjection. The sites for installing open loop heat exchangers have to be with productive aquifer(s), so that it is possible to pump and reinject groundwater efficiently. Closed loop heat exchangers (also called ground source heat pumps) are often made up of a group of U-tubes that are installed underground horizontally or vertically. In Beijing, they are often vertical U-tubes installed in boreholes, because horizontal U-tube systems often need plenty of land. For the ease of drilling the boreholes and installing the U-tubes, the sites have to be easy to drill to a proper depth (often about 100m). That is to say, if the shallow strata are made up of gravel and pebbles, the drilling will be difficult, and it will not be suitable to install down-hole heat exchangers.

This paper will focus on the underground part of GHP systems. The shallow geological conditions and the geothermal resources in the plain area in Beijing will be introduced, and the history and status of GHP utilization will be presented. The problems in the designing, installation and utilization of GHP will also be mentioned.

2. GEOGRAPHY

2.1 Climate

The climate is very different in the four seasons in Beijing. The spring is warm and windy, the summer is hot and rainy, the autumn is cool and clear, and the winter is cold and dry. The average annual temperature is about 13.5°C, and the highest and lowest daily average is 30.5 and -10.1°C in 2006 (Figure 1). The extreme high and low temperatures can be over 40°C and under -20°C respectively. In the summer, the air conditioning time is about 120 days, while in the winter; the heating season is also about 120 days.

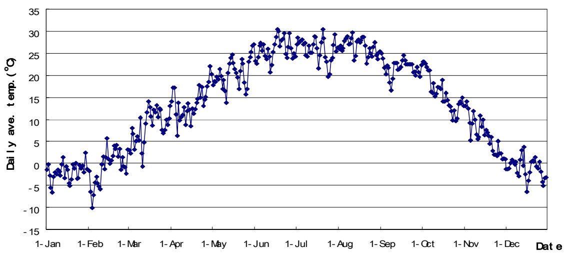

Figure 1: Daily average atmospheric temperature in Beijing in 2006

2.1 Topography

The area of the City of Beijing is about 16,800km^2, in which about 6,400km^2 is plain area (including Yanqing Basin in the Northwest) and about 10,400km^2 is mountain area. The total population is about 17 million, and most of them live in the plain area. There are more than a hundred rivers, belonging to five river systems. The most important ones are the Yongding River in the western part and the Chaobai River in the eastern part. Generally, it is higher in the north and west, and lower in the south and east (Figure 2).

Figure 2: A satellite image of the City of Beijing

3.CHARACTERISTICS OF QUATERNARY SYSTEM IN THE PLAIN AREA

3.1 Quaternary Sediments

The Quaternary sediments in the Beijing Plain are composed of the alluvial fans of the Yongding River and the Chaobai River, as well as the other rivers. In the upper parts of the alluvial fans, the sediments are thin and coarse, often composed of pebble, gravel and sand layers, where the aquifers are very permeable and with good water production capacity. Going down to the lower parts of the fans, the sediments gradually become fine and thick, often composed of silt and sand layers, where the aquifers are often not very permeable with low water production capacity (Figure 3 and Figure 4).

3.1 Zoning of Quaternary Sediments

As mentioned above, open loop GHP systems can only be used in areas with productive aquifers, and closed loop GHP systems are more suitable in areas without pebble and gravel layers. According to the hydrogeological conditions in Beijing, the plain areas can be divided into four zones, considering the suitability for open loop and closed loop GHP systems (Figure 3).

The first zone is in the upper parts of the alluvial fans, where the sediments are made of pebbles, gravels and sands mainly. A well drilled there can produce more than 3000 m^3/d of water. This zone is only suitable to open loop GHP systems.

The second zone is in the middle part of the alluvial fans, where the sediments are made of sand, gravel and silt layers mainly. The thickness of Quaternary is often greater than 100m. A well drilled in this zone can often produce 1,500-3,000 m^3/d of water. Generally, this zone is suitable to both open loop and closed loop heat exchangers.

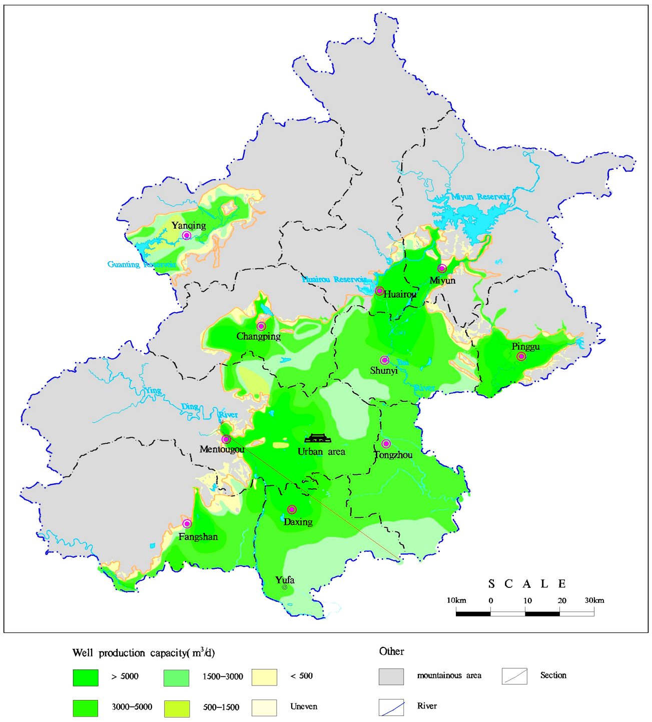

Figure 3: A hydrogeological map of Beijing Plain

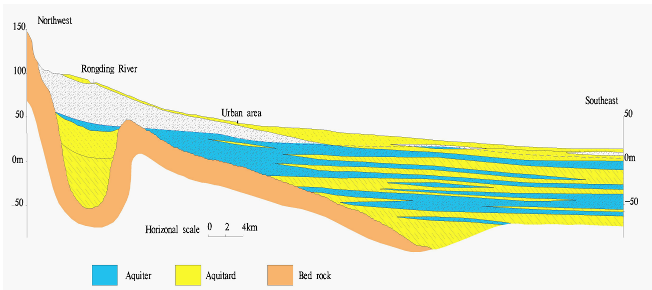

Figure 4: A hydrogeological cross section of the Beijing Plain

The third zone is mainly in the lower parts of the alluvial fans, where the sediments are mostly made of layers of fine particles. The aquifers in this zone are often not very productive, and the production capacity of a well is less than 1,500 m^3/d of water. This zone is generally only suitable to closed loop GHP.

The fourth zone is close to the mountain area, where the Quaternary sediments are often of proluvial and deluvial. In this zone, the thickness of the Quaternary is often less than 100m, and the sediments are composed of pebbles with clay and silt. The production capacity of the aquifers there is often not good. Generally, this zone is suitable to neither open loop nor closed loop heat exchangers. Only in local areas, it is possible to install open or closed loop heat exchangers.

3.3 Shallow Geothermal Resources

In the plain area of Beijing, the underground temperature at a depth of 70m is on average 13.5°C, and the highest and lowest are respectively 28.5°C and about 12°C (Liu et al., 2002). The temperature from the shallow aquifers is often around 15°C. This is very suitable for the operation of heat pump units.

The heat which can be obtained from the top 100 m of strata in a 1 km^2 area in Beijing is estimated about 2.1×10^{11} kJ if the temperature changes 1°C (Liu, 2008). In the area of Beijing, the difference of annual heating and cooling load is very small for most of the constructions. That is to say, if a GHP system used for a heating and cooling circle, the overall temperature change in the strata could be very small. In this case, the maximum capacity of GHP installations in the Beijing area mostly relies on the possible maximum difference of inflow and outflow temperatures in the summer. Normally, this temperature difference is taken to be about 10°C. Therefore, in an area of $1km^2$, the heat which can be obtained in a heating season in Beijing is about 2.1×10^{12} kJ. If the heating period is 120 days, and assuming the average heat load is $50W/m^2$, it can meet the heating needs of about 0.4×10^6 m^2 floor area. Of course, only a part of the areas could be used for installing GHP systems

4. HISTORY AND STATUS OF GHP UTILIZATION

4.1 General

Geothermal heat pumps had a fairly long history before the first two such projects were installed in Beijing in 2000. Both projects were open loop system, that is, there were well groups for pumping and reinjecting of groundwater. One of them is in the southern part of the city, and its service floor area is about $79000m^2$; the other one is for a hotel in the southwest part of the city, with a floor area of $13000m^2$.

Table 1. Historical Records of Number of Projects and Service Floor Area (from Wang et al., 2008)

Year	Number of projects		Service area (m^2)	
	Open loop	Closed loop	Open loop	Closed loop
2000	8	0	178,788	0
2001	23	2	518,097	17,087
2002	44	0	776,667	0
2003	76	4	1,800,473	64,509
2004	75	9	1,338,126	98,483
2005	64	8	1,377,919	410,937
2006	80	15	1,555,451	540,832
2007 (Jan.-Sept.)	45	26	976,865	872,838
Subtotal	415	64	8,522,384.89	2,004,685
Total	479		10,527,070	

Note: There is not a good statistics after September 2007.

After that, open loop GHP projects increased very fast, and there were 415 open loop systems at the end of September 2007, with a service area over than 8.5 million m^2. With the first one started in 2001, the development of closed loop GHP system was much slower than for the open loop systems. To the end of September 2007, there had only been 64 closed loop systems, and the service area was a little more than 2 million m^2 (Table 1). The number of projects is estimated as about 600 to the end of 2008, corresponding to about 13 million m^2 of floor area. Most of the GHP systems installed after 2008 are closed loop systems.

The types of constructions installed with GHP in Beijing include mainly office buildings, apartment buildings, schools, department stores, gymnasiums, hospitals, hotels, as well as swimming pools, scenery ponds, and greenhouses (Figure 5).

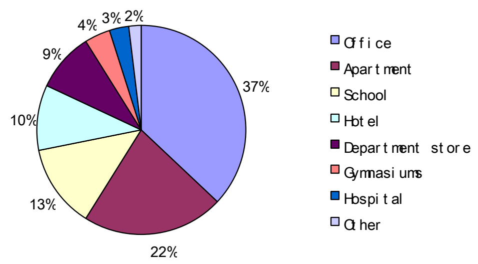

Figure 5: Category of buildings of GHP installation in Beijing (from Wang et al., 2008)

4.2 Open Loop Systems

As mentioned above, the GHP systems installed before 2006 are mostly groundwater source heat pumps, that is open loop heat exchangers. From 2003 to 2006, the number of newly installed such systems every year was 70 to 80. In 2007, a strict limitation on well design and drilling was applied in Beijing, including the limit for well distance and distance to buildings, as well as water supply well fields protection, and the number of open loop systems put into use decreased.

Open loop GHP systems are mostly installed in the western and southern part of the central area of the city, where the hydrogeological conditions are appropriate and the heating and cooling needs are extensive. In some of the area, there are 5 GHP systems in an area of 1 km^2. The biggest open loop GHP system in Beijing is in the southern part of the city. It is for a garments market with a 310000 m^2 floor area.

The wells for GHP systems need proper maintenance, especially reinjection wells. After operation for some time, the injection capacity of the wells will greatly decrease. The capacity of the pumping wells will also decrease with the operation going on. The wells should be regularly flushed, often once a year.

4.3 Closed Loop Systems

Before 2005, there were much less closed loop systems than open loop systems in Beijing, because the investment on a closed loop system is about 30% higher than that of an open loop system. Since 2006, much more closed loop systems have been put into operation, and more and more such systems are under construction, because of the limitation to wells for open loop systems. It is predicted that closed loop systems will expand much faster than open loop systems.

At present, about 60% of the operated closed loop systems are outside of the central area, and mostly in the north of the city, where it is not hydrogeologically suitable to open loop systems. At the beginning, the downhole heat exchangers were often of single U-tubes, and the boreholes often 150mm in diameter and 100m deep. Recently, the heat exchangers are more commonly double U-tubes. And the boreholes are 200mm in diameter and 100-150m deep. The diameter of the U-tubes is often 32mm. The distance between boreholes for U-tubes is 4 to 5m.

From the end of 2006, an assessment report on the geological conditions is required by the government before the construction of each closed loop system. This is for the purpose of avoiding risks and getting perimeters for the designing of the system. If there is any thick gravel or pebble layer(s) underground, the project may be rejected.

4.4 Problems

Many problems have been encountered in the design, installation, operation and management of GHP systems in the past several years in Beijing. These include:

(1) Observation of energy saving effect: although so many GHP have been operated in Beijing, the energy saving effect can still not be demonstrated clearly, because the electrical meters are not often dedicated to the GHP system. For further promotion of GHP, proper metering for new projects should be carried out.

(2) Designing of large scale projects: there have been a few large scale GHP systems in operation in Beijing, but experience is still lacking in the design of large scale projects, especially in the capacity testing of downhole heat exchangers and in deciding the distance between production and reinjection wells.

(3) Management of installation: it has been discovered that a small number of GHP systems can not operate efficiently, mostly because of faults in the installation of U-tubes and the well completion. The refilling of the U-tube boreholes should be strictly supervised. The screen installation, gravel packing and well flushing should be strictly controlled for ensuring the production and reinjection capacity, and to avoid high sand content of the pumped water of open loop systems.

(4) Monitoring and modelling of the thermal effect underground: the operation of GHP systems will certainly have influence on the temperature field underground. It is important to know the long-term thermal effects and the environmental impacts. Therefore, it is essential to have a proper monitoring program and set up appropriate models for prediction. The present monitoring system is very incomplete and should be improved as soon as possible.

5. EFFECTS OF GHP UTILIZATION

5.1 Economic Effects

To demonstrate the economic effects of GHP utilization, the initial investment and operation cost of heating for a building with 10,000m^2 of floor area is presented below, considering (1) oil boilers and associated facilities; (2) a closed loop GHP. The system was installed about 30km north of the central area. The investments and operation costs are as follows (Table 2).

It is predicted that after about 9 years of operation, the present value of oil boiler will be greater than that of the GHP system, and after 30 years of operation the present value of the oil boiler will be much greater than that of the GHP. In the prediction, the renewal of oil boiler and GHP are considered according to their life time (Figure 6). It means that the GHP system is economically rational compared to oil boilers. It should be mentioned here that the GHP system is also used for cooling and the actual economic effects will certainly be better than predicted above. Because it is not possible to have complete data, it is difficult to demonstrate the economic effects of all the installed GHP system in Beijing.

Table 2. Initial Investment and Annual Heating Cost of GHP and Oil Boilers.

Type of heating	Investment(Yuan)	Annual Operation costs (Yuan)
Oil boilers	50,000	881,900
GHP	440,000	410,000

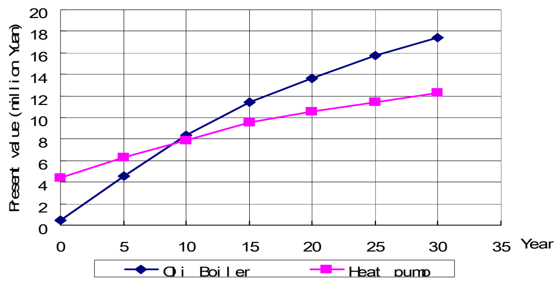

Figure 6: Present value of GHP and oil boilers (from Wang et al., 2008)

5.2 Environmental Effects

The environmental effects of the GHP systems operation in Beijing are remarkable. Considering the present service floor area of the installed GHP systems in Beijing, the installed capacity is about 980MW, and the amount of heat energy saved annually is estimated as 1.22×10^{10}MJ, accounting for the heat of 6.95×10^{5} tons of coal and 1.66×10^{6} tons of CO_2 emission reduction. From 2000 to 2008, the total amount of energy saving through the use of GHP systems in Beijing is estimated as 3.23×10^{10} MJ, accounting for the heat of 1.84×10^{6} tons of coal and 4.38×10^{6} tons of CO^2 emission reduction

CONCLUDING REMARKS

Geothermal heat pump systems are suitable to Beijing, considering the geological conditions at shallow depth and the climate characteristics. Since 2000, about 600 GHP systems have been in operation, and the service floor area has been over 13 million m^2 to the end of 2008, bringing great economic and environmental effects. The encouragements of the government played an important role in the promotion of GHP. Other cities in China have taken Beijing as an example in their GHP utilization. It can be foreseen that GHP systems will play a bigger role in the new energy use and CO_2 emission reduction strive in China. The design and installation of the underground part is the most critical step for the GHP systems. It is essential to have proper geological explorations before the designing of GHP systems. It is also important to study the thermal and environmental effects underground.

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