Beijing's Demonstration Activities in Geothermal Source Heat Pumps in China

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ABSTRACT

Beijing started with geothermal source heat pumps(GSHP) relatively earlier and now is one of the pioneer cities of this booming technology and market in China. There were more than 8 million m^2 building areas installed with geothermal source heat pumps, about 30 million m^2 are planed to be installed before 2010, most of which use underground water as the heat source. Owing to its environment-friendly and energy-saving characteristics geothermal source heat pump is on the one hand encouraged by some incentive policies and on the other hand is regulated by the government. Considering that about 335 million tons of standard coal will be saved with GSHPs in 2020 when there will be more than 70 billion m^2 building areas in China, it can be predicted that GSHPs will be the most favorable choice for space heating. The demonstration activities are discussed and analyzed in this paper.

1. Introduction

China is rich with low-medium enthalpy geothermal resource and has long history of using geothermal energy. The total direct use geothermal energy in 2005 was 12604.6 GWh with 3687 MWt installed capacity, including 65.2% balneology, 18.0% space heating, 9.1% agriculture and aquaculture, industrial applications, including heating, evaporating, drying, distillation, sterilization, washing, de-icing, salt-extraction, oil-recovery, milk pasteurisation, leather industry, chemical extraction, CO_2 extraction, laundry use, etc. 7.7%.

Space heating concentrated in the northern cities, such as Tianjin, Beijing, Xian and Daqing, where 60-100°C hot water is pumped directly to the buildings. Figure 1 shows space heating and hot water supply with low-medium geothermal water and the reduction of CO_2 and NO in the years from 1990 to 2005. There were buildings of 1.9 million m^2 in 1990, 8 million m^2 in 1999, and 12.7 million m^2 in 2005 heated with 60-100°C of underground geothermal water, a fast growth.

Comparatively GSHPs were started quite late but developed rapidly in China. From 1996, especially from the beginning of this century more than 20 million m^2 buildings have been conditioned with GSHPs, which exceeds the heated buildings with 60-100°C geothermal water. In addition more and more cities are planning to replace the traditional coal and oil/gas boiler with GSHPs. Shenyang, the capital of Liaoning province, had about 3.12 million m^2 being heated with geothermal source heat pump at the end of 2006, and there are 15 million m^2 being installed with GSHP this year, and 65 million m^2 are planned up to the end of 2010. Lhasa, the capital of Tibet, where about 50% of the total electricity consumption has been supplied by geothermal power station from Yangbajing, is now planning to provide its space heating with GSHP to improve the life of this city and to provide a more comfortable environment.

Owing to its energy-saving and environment-friendly competitive advantages GSHPs are supported by governmental incentive polices. The government started to collaborate on renewable energy under the Cooperation Agreement about Geothermal Production and Application signed by China

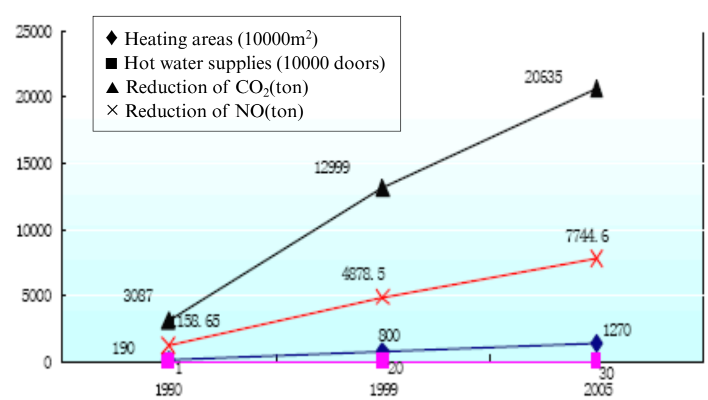

Figure 1. Space heating and hot water supply with geothermal water and reduction of CO_2 and NO.+

Science and Technology Committee and America Energy Department in November 1997. Then three companies were founded in Beijing, Shanghai and Guangzhou in 1998, and three GSHP systems with the entire building areas of 132 380 m^2 were installed as demonstration projects in each city in 1999, of which the Jiaheyuan International Apartment has the largest area of 88 000 m^2. In terms of both installed capacity and energy of geothermal heat pump utilization, China is ranked third in the whole word in 2006. In this paper Beijing's activities in geothermal heat pumps are discussed.

2. The Installations of Geothermal Source Heat Pump in Beijing

As the capital of China, Beijing started with GSHPs earlier than other cities, and is nowadays one of the pioneer cities for GSHPs in China. Up to the end of 2006, including 2008 Beijing Olympic Bicycle, Shooting Gymnasium and 2008 Beijing Olympic Yinddong Swimming Pool, there were more than 8 million m^2 buildings in Beijing installed with GSHP as air-condition system to supply heating in winter, cooling in summer and hot water for the whole year. About 30 million m^2 are planned to be built in the 11^{th} Five-Year period of China, from 2006 to 2010. The installed building with GSHPs covers residential housing, office building, hotel, school, kindergarten, marketplace, old people's home, gymnasium, factory building, sewage disposal center, sightseeing pool, villa etc. Table 1 shows some representative GSHPs installed in Beijing, most of which were installed in the last few years.

Table 1. Some representative of GSHPs installed in Beijing.

Type of Building	Geology	Flow Rate/ well (m^3/h)	Heat source	Production Wells + Injection Wells	Depth (m)	Building areas (m^2)	Investment (Million RMB)
Police College	Dolomite	150	Underground water	6+6	350	180 000	13
Friendship Hospital	Gravel	150-200	Underground water	6+7	80	130 000	7
International Apartment	Sand, Gravel	200	Underground water	2+2	160	88 000	25.24
Friendship Hotel	Gravel	200	Underground water	2+3	100	51 000	12
Foreign Language Institute	Gravel	90	Underground water	2+2	100	30 000	
Changping Training Center	Sand, clay	<50	BHE	348	115	38 000	4
Changping Toll	Sand, clay	<50	BHE	183	100	10 000	4

Note: the exchange rate in May 2006 was about 8 Yuan RMB for 1 US $

From Table 1 we can see that most of GSHPs are water source heat pump using groundwater as the heat source, and the quotient of ground-coupled heat pumps with borehole exchanger is relatively small. Though injection wells are drilled to re-inject the water to the formation where the water was pumped, there still remains some questions to be discussed and considered, such as whether the water can be re-injected completely, how much underground water can be exploited, and how the biological environment can be affected, and so on.

3. The Governmental Policies and Regulations

GSHPs are supported and regulated by Beijing government. In May of 2006 Beijing Municipal Commission of Development and Reform issued a guiding opinion to develop heat pump system, in which there is an incentive to install waste water, surface-underground water, and ground-coupled heat pumps. For the office buildings, such as, school, hospital, administration garden concerning the public interest, the government will provide the initial investment, for the others the government will provide subsidies with 35 Yuan RMB per m^2 for surface and underground water source heat pump, 50 Yuan RMB for ground-coupled and waste-water heat pump. (Note, the exchange rate in May 2006 was about 8 Yuan RMB for 1 US $).

In August 2006 Beijing Land and Resource Bureau issued a provision to regulate the GSHP installation, in which it is required to apply for a permission from the Beijing Land and Resource Bureau by providing the corresponding geological, hydrological and geothermal investigation report in advance.

4. Measure of Geothermal Properties in Olympic Forest Garden

Complying with the provision issued by the Beijing Land and Resource Bureau, a completed investigation on the

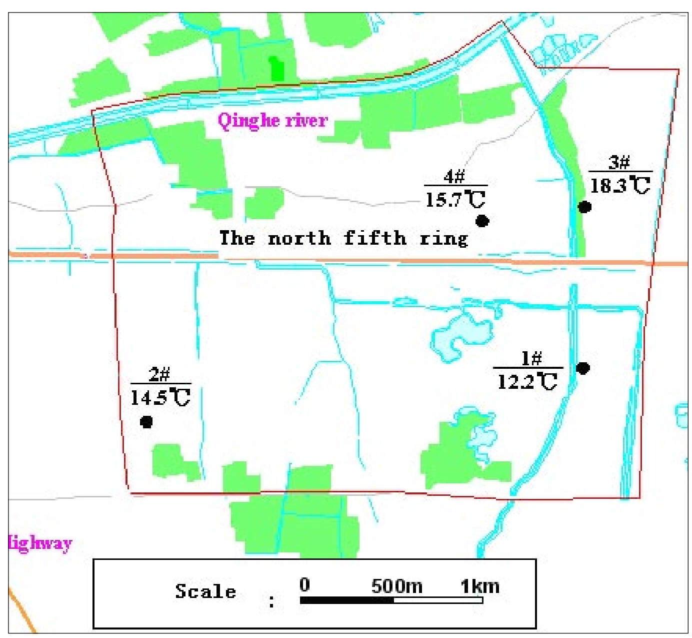

Figure 2. The distribution of measured holes in Beijing.

geological, hydrological and geothermal characteristics was implemented and analyzed in 2006. Olympic Forest Garden lies in the northern part of Olympic zone, a neighbor of the Bird-Nest main gymnasium. The total area of the garden is 6.8 million m^2, and about 30857m^2 buildings are planned to install ground-coupled heat pumps. In the following the geothermal property measure is introduced and the result is discussed and analyzed. The distribution of the measured holes is showed in Figure 2.

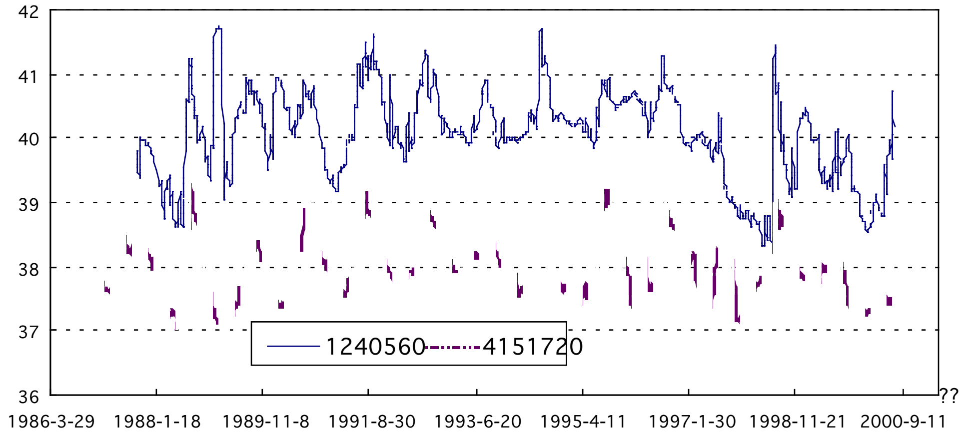

Figure 4. The dynamic water table within the depth of 30 meters.

The Geological Conditions

Olympic Forest Garden is located in the middle part of Yongding River alluvial fan deposit. Figure 3 shows that the strata profiles are mainly made of clay, silty soil and sandy gravel with different thickness from 40 to 125 meters. The measure of geothermal properties is limited within the Quarternary deposit.

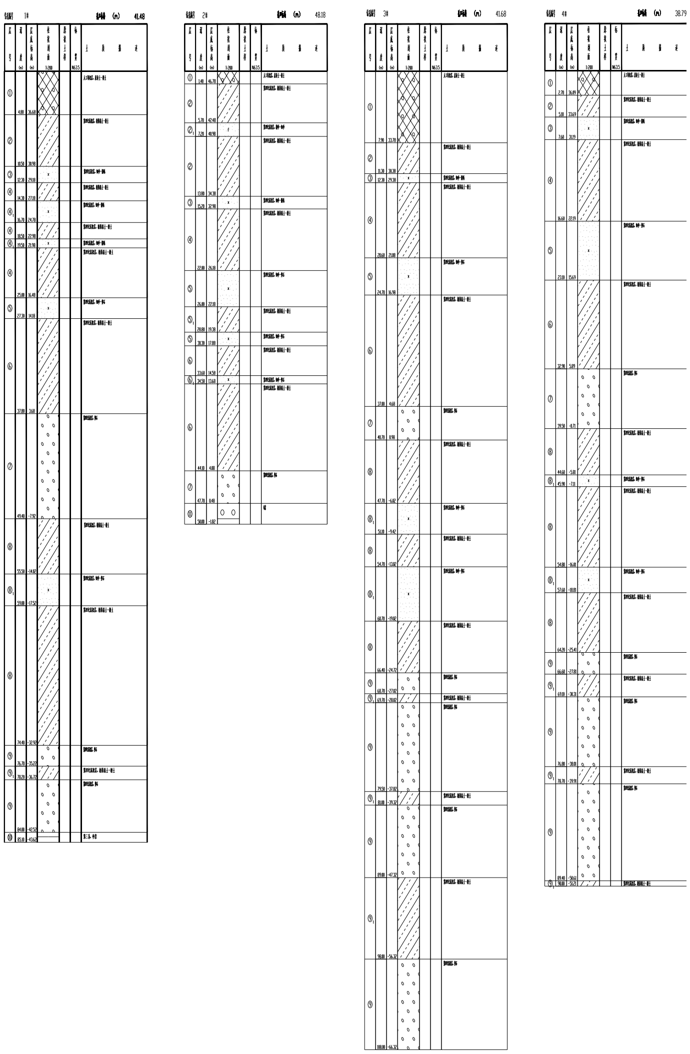

Figure 3. The strata profiles of the tested holes.

The Hydrological Conditions

The groundwater in the Quarternary deposit is divided into two groups based on its depth, the shallow one from surface to the depth of 30 meters, and the deep one from 30 meters to the depth of bed rock. The upper shallow groundwater with about 1.20‰ of hydraulic gradient is divided into two groups. One of them stored in the sandy soil and gravel of the old stream with 20 m/d permeability, flows in the direction of northwest-southeast in the west part of the garden and southwest-northeast in the east part at a speed of 2.40×10^{-2}m/d, the other is stored in the silty soil, sandy soil and gravel of the mesa-butte with 10 m/d permeability, with flows from west to east at a speed of 1.20×10^{-2}m/d. The deep groundwater is stored in the sand and gravel formation with 60 m/d permeability, and flows also west to east at a speed of 9.00×10^{-2}m/d with about 1.50‰ hydraulic gradient.

Figure 4 shows that the dynamic water table within the depth of 30 meters changes corresponding to rainfall, i.e. increases in the months from June to September during rainy season and decreases in the other months.

Figure 5, overleaf, shows that the dynamic deep groundwater table which is influenced by rainfall and exploitation. Due to overexploitation it had dropped greatly since 1960's. In 1980's the decline was controlled and the water table rcovered to a certain extent, but dropped again because of less rainfall since 1999.

The Estimation of Ground Thermal Properties in Olympic Forest Garden

Referring to the thermal conductivities for the soil and rock classifications, the weighted arithmetic averages of the thermal

Table 2. The weighted arithmetic averages of the thermal properties for each tested borehole.

Tested Bore-holes	Thermal Conductivities (W/m.°C)	Mass Specific Heat Capacity (J/g.°C)	Heat Diffusivities (m^2/h)
1	1.575052	1.108695	0.002482
2	1.467132	1.015506	0.002562
3	1.719158	1.158112	0.002548
4	1.701736	1.170512	0.002498

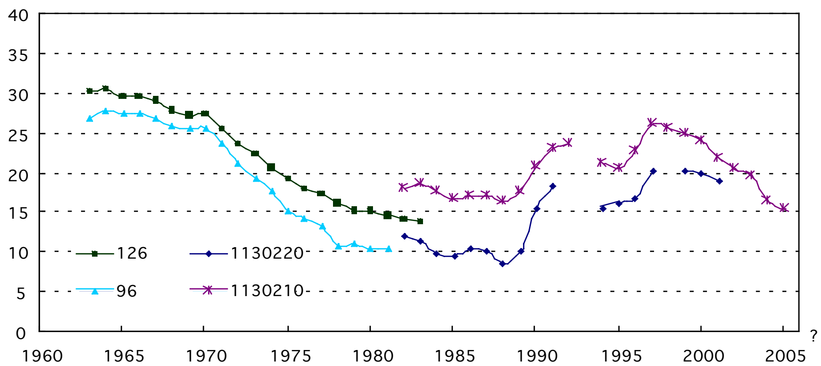

Figure 5. The dynamic deep groundwater table.

conductivity, mass specific heat capacity and heat diffusivity for each tested hole were estimated, the results are showed in Table 2, previous page.

The Measurement of Ground Thermal Properties in Olympic Forest Garden

The measurement was executed with an in situ thermal property tester developed by China University of Geosciences, which is illustrated in Figure 6 and its testing principle in Figure 7. Line source model was used to calculate the geothermal parameters. Line source model was established based on approximating the borehole as a line source, assuming the end effects are small. The soil acts as a heat rejection medium that has an assumed uniform and constant initial temperature. The line source model is expressed in equation (1), the calculated conductivities with the line source model are described in table 3, and the tested temperature and calculated temperature is compared in Figure 8.

$$T_f = T_{ff} + q_l \cdot \left[R_o + \frac{1}{4\pi k_s} \cdot Ei\left(\frac{d_b^2 \rho_s c_s}{16 k_s \tau} \right) \right] \quad (1)$$

Where, $Ei(x) = \int_x^{\infty} \frac{e^{-s}}{S} dS$;

T_f —average temperature of fluid in U-tube, °C;
T_{ff} —soil/rock temperature at infinite distance far from borehole, °C;
d_b —borehole diameter, m;
c_s —soil/rock specific capability, W·s/kg. °C;
k_s —soil/rock thermal Conductivity, W/m·°C;
q_l —heat flow per unit borehole length ,W/m;
R_o —heat resistance per unit borehole length,°C·m/W;
ρ_s —density of soil and rock, kg/m^3;
t —time, s.

As we know that the heat conductivity changes greatly even for the same kind of soil or rock according to the soil and rock classifications, Table 3 demonstrated that there are relative errors between the estimated weighted arithmetic averages of the thermal properties and the calculated conductivity with line source model for each tested borehole, because of different hydrological conditions. Figure 8 indicates that the tested temperature and calculated temperature correspond quite well, which supported the results of the calculated conductivity with the line source model.

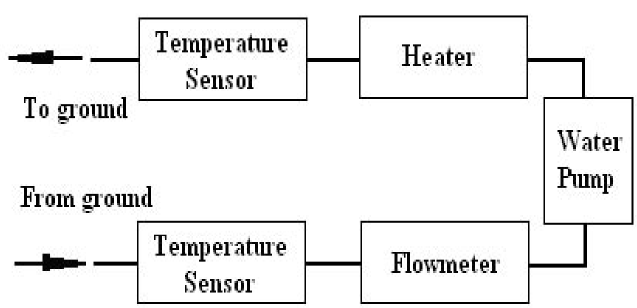

Figure 6. Illustrated geothermal property tester.

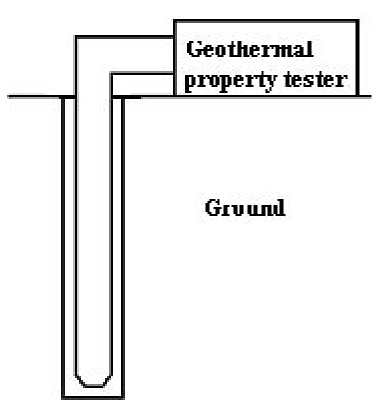

Figure 7. Scheme of testing priciple.

Table 3. The calculated conductivity with line source model and comparison with weighted arithmetic average conductivity.

Test Bore-holes	Depth (m)	U-Type	Weighted Arithmetic Average Conductivity (W/m·°C)	Calculated Conductivity with line Source Model (W/m·°C)	Relative Error
1	82.8	Double	1.575052	2.030	+28.9%
2	49	Double	1.467132	1.754	+19.6%
3	104	Single	1.719158	1.385	-19.4%
4	86	Single	1.701736	2.065	+21.3%

5. The Development of GSHPs in China

Owing to its environment-friendly and energy-saving characteristics it can be predicted that geothermal source heat pumps will prosper in the near future[5]. From the demonstration in Beijing there are some suggestion listed as follows:

- GSHPs have many advantages to be the first choice for heating, cooling and hot water supplying, anywhere, especially in areas where there is lack of conventional fossil energy, where the entironment is relative fragile, where the residents are rare and scattered, and so on.

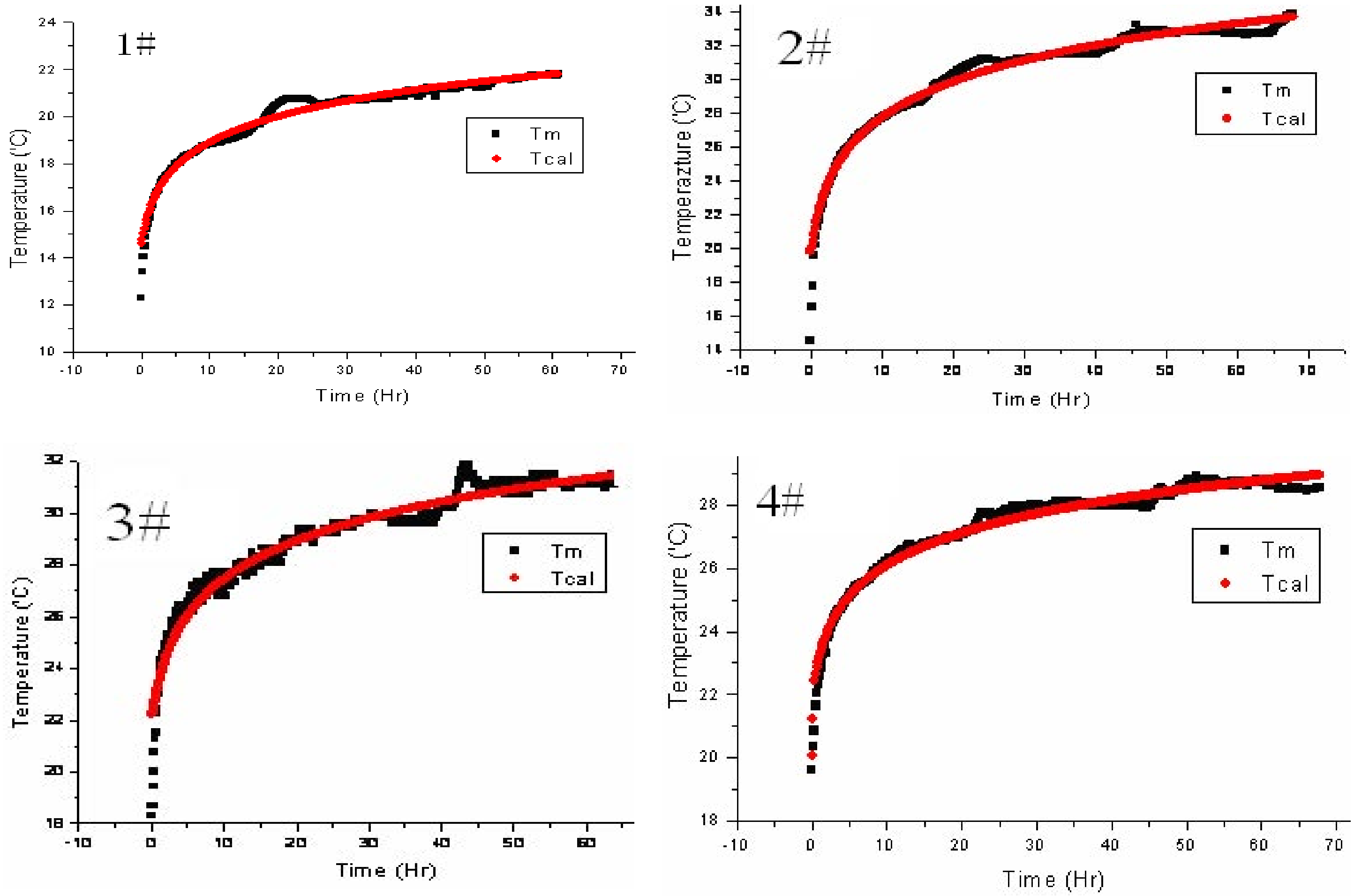

Figure 8. The tested temperature and calculated temperature.

- The technology and efficiency of GSHPs are still to be developed and improved, and the government will play significant roles to encourage and sustain GSHPs in many aspects by favorable policies, and specifications.
- The geological and hydrological conditions should be considered to install GSHPs to avoid groundwater over-exploitation and significant environmental disturbance.

References

1. John W. Lund, Derek H. Freeston and Tonya L. Boyd, 2005. "World-wide direct uses of geothermal energy 2005", Proceedings World Geothermal Congress, No. 0007, 1-20.

2. R. Curtis, J. Lund, B. Sanner, L.Rybach, G. Hellstrom 2005, "Ground source heat pumps-geothermal for anyone, anywhere: current world-wide activity". Proceedings World Geothermal Congress 2005, No. 1437, 1-9.

3. Warren Adam Austin, 1998. "Developmemt of an In Situ System for Measuring Ground Thermal Propertes", thesis of MASTER OF SCIENCE, Oklahoma State University.

4. Heyi Zeng, Zhaohong Fang, 2003. "Double U-Type Ground Exchanger Heat-transmission Model", Journal of Shandong Architecture Engineering, v.18 No.1, p.11-17.

5. Xiuhua Zheng, 2003. "The Feasibility and Technology to Develop the Chinese Potential Market of Geothermal Source Heat Pump Systems". Geothermal Resources Council Transactions, v. 27, p. 119-121.