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Research on Large Scale Application of Shallow Geothermal Resources in Beijing

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ABSTRACT

Compared with conventional geothermal energy, shallow geothermal energy is widely distributed and easy to exploit, which is an ideal heat or cooling source for buildings. As the capital of China, Beijing is one of the earliest cities which develop and utilize shallow geothermal energy. The application area of ground source heat pump projects has an annual growth rate of over 150% in recent years since the first ground source heat pump project was completed in 2000. The total application area was more than 38,000,000 square meters in Beijing by 2012. This paper proposed appropriate modes of development, utilization, and dividing the suitable areas of shallow geothermal energy according to the resource conditions of shallow geothermal energy in Beijing. In association with the city construction planning of Beijing, it also forecasted the prospects for shallow geothermal energy development and utilization and the expected economic and environmental benefits. In the end, it discussed the key technical problems of large scale application of shallow geothermal energy based on the successful experiences in the ground source heat pump project construction, operation management and monitoring. According to the monitoring data of Beijing's ground source heat pump projects, the utilization of shallow geothermal energy for large-scale building heating and cooling has significant energy saving benefits. The development and utilization of shallow geothermal energy has great importance for relieving energy shortage, improving energy structure, and shifting to low-carbon economical society in Beijing.

1. INTRODUCTION

Shallow geothermal energy is contained in soil, rock, groundwater, and surface water at a depth up to 200 m. The temperature of shallow geothermal source is usually below 25℃. Shallow geothermal energy is a type of geothermal energy, which is produced by deep geothermal energy and solar energy. Shallow geothermal energy, which has a wide distribution and large reserves, is a kind of clean and renewable energy. Compared with deep geothermal energy, shallow geothermal energy can be easily exploited under current technical and economic conditions. As the capital of China, Beijing faces energy shortages and environmental pollution problems along with the rapid development of economics in recent years. From the current energy use situation of Beijing, building energy consumption accounts for about 32% of all energy consumption and air-conditionings contribute about 50% of building energy consumption. According to a survey in Beijing, 17% of PM2.5 in the atmosphere comes from the power plants, boilers, and coal emissions. Because of the shortage of wind energy and hydropower resources in Beijing, using the shallow geothermal energy for building heating and cooling is an effective way to improve the energy structure and to reduce the air pollution.

2. THE UTILIZATION TECHNOLOGY OF SHALLOW GEOTHERMAL ENERGY IN BEIJING

The temperature of soil and water below 30m depth is not affected by weathers, and varies from 14℃ to 16℃at the depth between 30 m to 200 m. Ground source heat pump is the main method of shallow geothermal energy resource exploitation. Depending on the different forms of the geothermal exchange system, the groundwater source heat pump system and ground source heat pump system are widely used in Beijing.

The groundwater source heat pump system uses groundwater as heat source and sink. The construction of groundwater source heat pump system is easy and cheap. The groundwater source heat pump system occupied less space at the same time to satisfy the building cooling and heating demands. But its application is largely restricted by hydrogeology condition. Only in the areas which have rich, stable, and good-quality groundwater and are easy to recharge, it is suitable for the construction of groundwater source heat pump system. In recent years, the increasingly stringent groundwater exploitation policies further limit the development of groundwater source heat pump system in Beijing.

Ground source heat pump system which transfers heat from soil and groundwater through underground heat exchangers to is categorized into horizontal buried pipe system and vertical buried pipe system. Because of the limited land resource in Beijing, the vertical buried ground source heat pump system is popularized in recent years. Compared with the conventional air-conditioning system and groundwater source heat pump system, the ground source heat pump system initial investment is high, but it is less restricted by hydrogeology condition and less affects on the environment of underground space. In recent years, ground source heat pump system is more widely used to solve the problems of limit land resource and high initial investment compared with conventional energy system and thermal storage technology.

3. DEVELOPMENT AND UTILIZATION STATUS OF SHALLOW GEOTHERMAL ENERGY IN BEIJING

Beijing is one of the earliest cities which have developed the shallow geothermal energy in China. Since 2000, groundwater source heat pump system and ground source heat pump system are gradually used in hotels, hospitals, schools and office buildings. After years of development, the ground source heat pump projects and service areas of ground source heat pump projects are increased rapidly.

According to incomplete statistics, the total number of groundwater source heat pump projects and ground source heat pump projects has reached 724 in 2010. The area of building cooling and heating is about 19,570,000 square meters. The total amount of groundwater source heat pump projects has reached 515, and the area of building cooling and heating is about 12,090,000 square meters which accounts for 62% of the total area. The total amount of ground source heat pump projects has reached 209, and the area of buildings used shallow geothermal energy for cooling and heating is about 7,480,000 square meters which accounts for 38% of the total area.

Groundwater source heat pump projects are mainly distributed in Haidian, Chaoyang and Fengtai, and the building area in them accounts for 54% of the total area of groundwater source heat pump projects. Ground source heat pump projects are mainly distributed in Shunyi, Haidian and Chaoyang, and the building area in them accounts for 62% of the total area of ground source heat pump projects.

The suitable project types for groundwater source heat pump system and ground source heat pump system include office buildings, residences, schools, hospitals, hotels, industrial plants, natatoriums, greenhouses, and landscape pools. Shallow geothermal energy is widely applied to public building cooling and heating. The area of public buildings used shallow geothermal energy for cooling and heating accounts for 77% of the total area.

Since 2001, the average annual increase of the service and amount of the ground source heat pump projects is more than 150%. The speed of shallow geothermal energy development and the application scale are leading other cities in China. According to incomplete statistics, the total number of groundwater source heat pump projects and ground source heat pump projects has reached 1146 in 2012. The area of buildings using shallow geothermal energy for cooling and heating is about 38,000,000 square meters and the area of the largest building is more than hundreds of thousands of square meters.

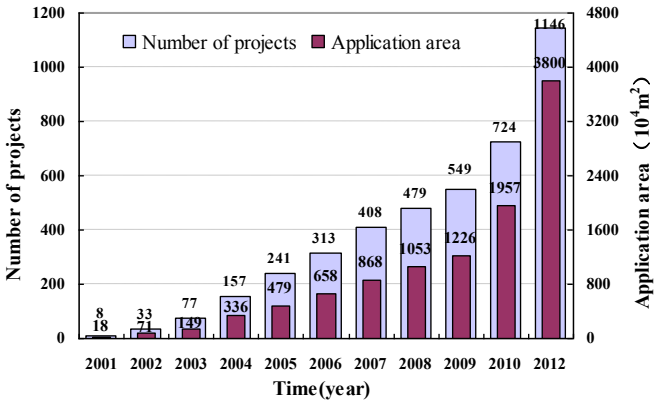

Figure 1: The development tendency of ground source heat pumps in Beijing (2001-2012)

3. SHALLOW GEOTHERMAL ENERGY RESOURCES OF BEIJING

3.1 Shallow geothermal energy resources condition

Shallow geothermal energy resource condition is closely related to the geology, geography, meteorology, topography and groundwater. The temperature of Beijing is in the range of 10℃ to 12℃. The climate of Beijing is hot in summer and cold in winter, which determines the characteristics of energy demands. So Beijing is suitable to use shallow geothermal energy resources for building cooling and heating. Shallow ground temperature in most area of Beijing plain is between 14.5 to 16.5 which is slightly higher than the annual average temperature. It is more suitable to use the ground source heat pump system for shallow geothermal energy exploitation.

River network is developed in Beijing plain which is composed of alluvial fan and lacustrine plain. Quatemary sedimentary strata thickness increases gradually and sediment particles become thinner from the northwest to the southeast of Beijing plain. In the upper part of alluvial fan, quatemary sedimentary strata thickness is between 20m and 40m, and the strata are composed by sand layer, gravel layer or cobble layer. Also the groundwater runoff is strong in this area. In the lower part of the alluvial fan, quatemary sedimentary strata thickness increases gradually and the thickness reaches more than 500m in Shunyi depression, Pinggu depression and Ma-chikou depression. The strata in this area are usually composed by sand layer and clay layer and the groundwater runoff in this area is gradually slow.

3.2 Suitable area of shallow geothermal energy resources exploitation

This paper divided the suitable area of shallow geothermal energy development and utilization by analytic hierarchy process based on the factors of hydrogeological conditions and geological environment.

The suitable area and less suitable area of groundwater source heat pump system in the upper part of alluvial fan of Beijing plain are about 1080 km^2. Quatemary sediment particles are more crude and the strata are composed of sand layer, gravel layer or cobble layer in the suitable area and less suitable area of groundwater source heat pump system. Water resource is rich in this area. Generally, the water yields at a speed of more than 3000 cubic meters per day and the withdrawal-recharge ratio may reach 1:2 or higher. It should be noted that, due to the excessive exploitation of groundwater in Beijing for many years, the groundwater level declines rapidly in the area near mountains and the effective aquifer thickness is less than 10m. So, this area is not suitable for establishing groundwater source heat pump system. Protection areas of groundwater source, land subsidence area which cumulative

settlement is more than 500mm, and geological disaster prone areas is prohibit to establish groundwater source heat pump system. The prohibition area is about 1118 km^2.

The suitable area and less suitable area of ground source heat pump system in the lower part of alluvial fan of Beijing plain is about 5169 km^2. Quatemary sediment particles are thin and the strata are composed of sand layer and clay layer in the suitable area and less suitable area of groundwater source heat pump system. Generally, the quatemary sedimentary strata thickness is more than 50m and the withdrawal-recharge ratio may less than 1:2. But it is suitable for establish ground source heat pump system and the investment for establish ground source heat pump system is low.

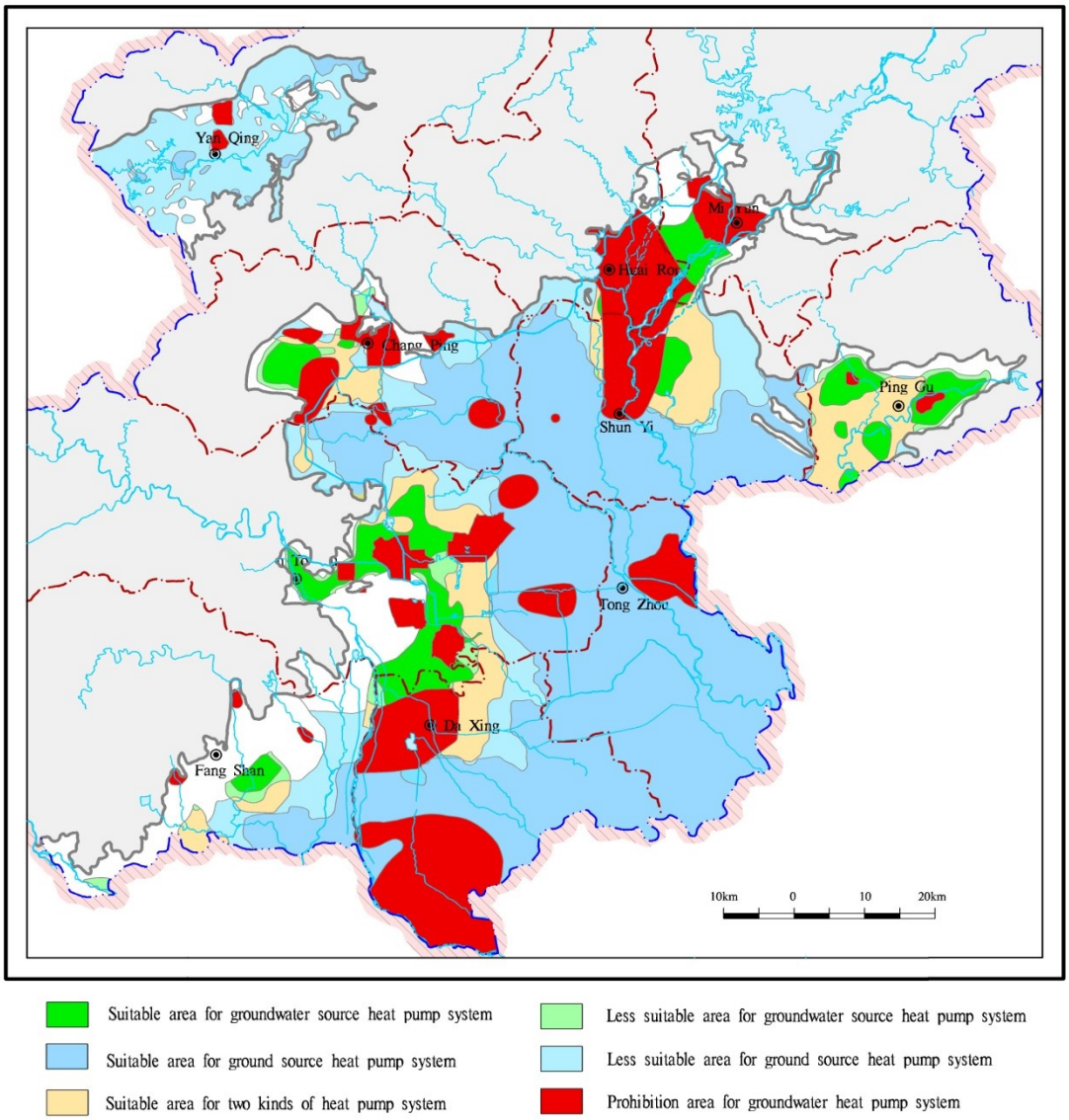

Figure 2: Suitable area of ground source heat pump system in Beijing

3.3 Evaluation of shallow geothermal energy resources

3.3.1 Heat capacity evaluation of shallow geothermal energy resources

The heat capacity of shallow geothermal energy resources is evaluated by geothermal reserve method, and the evaluation can be divided into the vadose zone and saturated zone. The evaluation area includes suitable area and less suitable area of ground source heat pump system. The evaluation depth of groundwater source heat pump system is 100m, while the evaluation depth of ground source heat pump system is 150m. According to the calculation results, the heat capacity of shallow geothermal energy in Beijing plain is $1.95x10^{15}$ KJ.

3.3.2 Potential capacity evaluation of shallow geothermal energy resources

The situation of city development, building load demands, shallow geothermal energy resources conditions and forms are important factors which are necessarily considered when evaluate the potential resources of shallow geothermal energy.

The following equation is able to evaluate the potential resources of groundwater source heat pump system.

$$Q_h = q_W \rho_W C_W \Delta T \times 1.16 \times 10^{-5} \quad (1)$$

where Q_h, q_w,ρ_w,C_w,ΔT are the shallow geothermal exchange power of well, the pump age of well, the density of the groundwater, the specific heat capacity of the groundwater, and using temperature difference of groundwater, respectively.

In the suitable area and less suitable area of groundwater source heat pump system, the distance from pumping well to recharge well is no less than 50m, and the distance betweem pumping wells is no less than 100m. According to the calculation results, the potential resources of shallow geothermal energy in suitable area and less suitable area of groundwater source heat pum system is about 5.19×10^6 KW in summer and 2.59×10^6 KW in winter.

The following equation evaluates the potential resources of ground source heat pump system.

$$D = k_z \times \Delta T \times L / 1000 \quad (2)$$

where D, k_z, ΔT, L are the shallow geothermal exchange power of hole, the complex heat transfer coefficient, the temperature difference of heat transfer and length of heat transfer hole.

According to the calculation results, the potential resources of shallow geothermal energy in suitable area and less suitable area of ground source heat pum system is about 3.86×10^7 KW in summer and 2.16×10^7 KW in winter.

The shallow geothermal energy resources in Beijing can applicated to 7.21 billion of building cooling and heating when the cooling load is 70 w/m^2 in summer and heating load is 50w/m^2 in winter.

4. PROSPECTS OF LARGE SCALE APPLICATION OF SHALLOW GEOTHERMAL RESOURCES IN BEIJING

In recent years, shallow geothermal energy has been widely used in many key projects in Beijing such as UF Software Park and the International Flower Port, etc. By the end of 2012, about 447,000 tons of standard coal have been saved when we use the shallow geothermal resources every year in Beijing. It means that about 1.456 million tons of pollutants, such as carbon dioxide, carbon dust, sulfur dioxide and nitrogen oxides, would be reduced to discharge into the air. According to research results on energy consumption of the typical ground source heat pump projects in Beijing, ground source heat pump system can save about 45% energy than traditional cooling and heating systems per unit area. The development and utilization of shallow geothermal energy create significant economic environmental benefits. Combined with Beijing urban development planning and the resource conditions of shallow geothermal energy, by 2020, the service area of shallow geothermal energy will be 8,000 square meters. It is about 11% of Beijing planned GFA. About 1,010,800 tons of standard coal has been saved per year and about 3.288 million tons of pollutants, such as carbon dioxide, carbon dust, sulfur dioxide and nitrogen oxides, will be reduced to discharge into the air. The development and utilization area of shallow geothermal energy will also be gradually expanded from the city center to the New Town and key towns. Application areas will gradually expand from public buildings to residential, modern agriculture greenhouse, industry and other fields. The coverage will be more widely.

5. PROBLEMS NEEDING ATTENTION IN THE UTILIZATION OF SHALLOW GEOTHERMAL ENERGY

For scientific and effective utilization of shallow geothermal energy, we propose problems needing attention according to the exploration, design, and construction and operation experience of the projects in Beijing. First, we should carry out a detailed site survey. Site survey includes on-site survey and geological prospecting. On-site survey is investigation on site conditions surrounding the project, building type, load demand, above and below ground structures and piping distribution. Geological prospecting is about hydrogeological data collection and parametric test. Survey data is the basis for project design.

Ground source heat pump extracts heat from the ground during the winter heating and discharges heat to the ground during the winter cooling. Due to the different cooling and heating load, the long-run heat pump systems can cause changes in the geothermal field. This change will lead to reduced system performance year after year and make saving and environmental protection benefits decline. Using auxiliary cold heat source to supplement can avoid the imbalance between cold and heat, lower initial investment of the system and make the heat pump systems become more scientific and rational.

After completion of the project, we should establish the appropriate mechanism of operation and the mechanism of monitoring and evaluation. We should regularly maintain on system equipment, monitor the power consumption during the ground source heat pump operation and monitor the impact of the geothermal field and groundwater quality, etc. We should also predict the impact on the geological environment while the ground source heat pump operates long-term stably.

6. CONCLUTIONS

The shallow geothermal energy resource is rich and the technology of development and utilization is relatively mature in Beijing. Combined with development status, there are broad prospects for shallow geothermal energy and significant environmental and economic benefits in Beijing. Large-scale application of shallow geothermal resources in Beijing has important significance for easing energy shortage, improving the energy structure, and transition to low-carbon economy.

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