

Analysis of the Influence of Borehole Depth on Energy Efficiency and Cost of Ground Source Heat Pump System

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Abstract

Ground source heat pump system has been widely used for its clean and efficient in China. The thermal properties of soil have great influence on the heat transfer effect of borehole exchanger. The borehole depth under different geological conditions have a significant impact on the energy efficiency of the ground source heat pump system and the cost of the project. A project was simulated as an example in this paper. The energy efficiency and the cost are calculated in different borehole depth but same load demands. The result shows that, the deeper the borehole is, the more energy efficiency the GSHP system can get in the project. Two typical geological conditions are selected in this paper. In the first geological condition, increasing the drilling depth is an efficient method to improve the energy efficiency of GSHP system, the borehole depth has little influence on the cost. In the second geological condition, shorter borehole exchanger can get more benefits because the drilling depth has a significant impact on the cost.

Keywords: Ground source heat pump; energy efficiency; cost

1. Introduction

In recent years, the problem of air pollution has become increasingly intensifying. In January 2013, the ratio of days for China's 74 cities whose air quality exceeding standard overall was 68.4%, the proportion of severe pollution and serious pollution reached 30.2%, among which PM_{2.5} (the fine particulate matter in the air whose particle size is 2.5 μ m or less) exceeded standard particularly seriously, on average, up to 68.9%. The maximum average concentration in 24h was 766 μ g / m³. So, the pressure on energy saving and emission reduction was unprecedented. Under this background, the GSHP, as a kind of energy-saving technology, driven by the relevant policies in recent years, has acquired widespread application. It was used in various climate regions, various types of buildings. Figure 1 shows the application area of GSHP system in China. However, high initial investment limit the GSHP system application. Most project dependent on state policies and financial subsidies.

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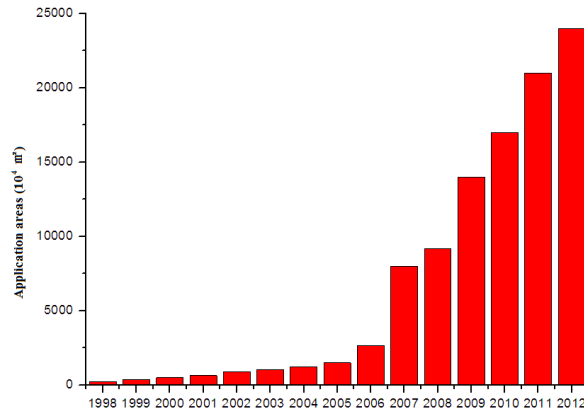


Fig. 1. Application area of GSHP system in China

GSHP system can supply heating in winter and cooling in summer, the earth is used as heat source in winter and heat sink in summer. The temperature distribution in the earth, and the heat transfer efficiency between the borehole and the soil are impact on the energy efficiency of the GSHP system directly. The earth as an energy storage in the GSHP system, the heat mainly comes from condensation heat of GSHP system, solar radiation of the earth surface, and a small part of the heat from the depths of the stratum. So, if the volume of energy storage is the same, can you get the same level of energy efficiency? Is it possible to reduce the initial investment by reducing the drilling depth? In this paper, the influence of the borehole depth on the energy efficiency and cost of the GSHP system is discussed through the demonstration of a project.

2. Project overview

The project is a seven-story office building for a college in Henan Province. The height of the office building is 30.3 m. Air conditioning area is about 23,000 m², the standard floor is shown in Figure 2. The office building is divided into four areas, including the west exhibition hall area, the south office building, the north office building and the east conference area. Fan coil system is used in summer for cooling, floor radiant system is used in winter for heating.

This project used the borehole thermal exchangers and GSHP units to take all the heating load in winter, and all the cooling load in summer. At the same time, the municipal heating network was used as backup system to improve heating safety assurance.

According to the local climatic conditions and building parameters, the building's cooling load and heating load are calculated, the results are shown in Figure 3. The cooling peak load is about twice as much as the heating peak load, the total heating load is $149.2 \times 10^3 \text{ kWh}$, and the total cooling load is $106.6 \times 10^3 \text{ kWh}$. The cooling season is shorter than heating season, and the GSHP system is set to operate all day in winter, only operate in work time in summer. So, the total heat released to the earth and the heat absorbed from the earth is basically the same. It is an assurance to GSHP system operate for many years efficiently.

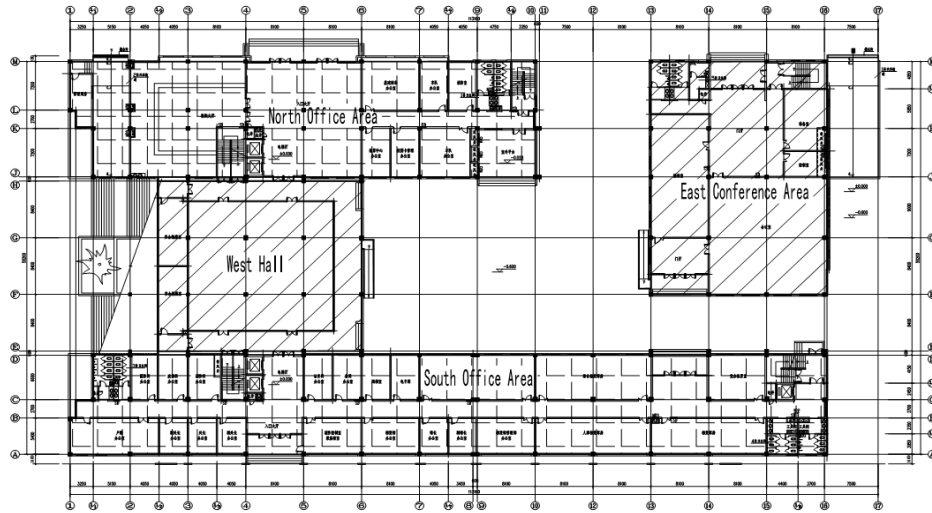


Fig. 2. Schematic diagram of office building floor

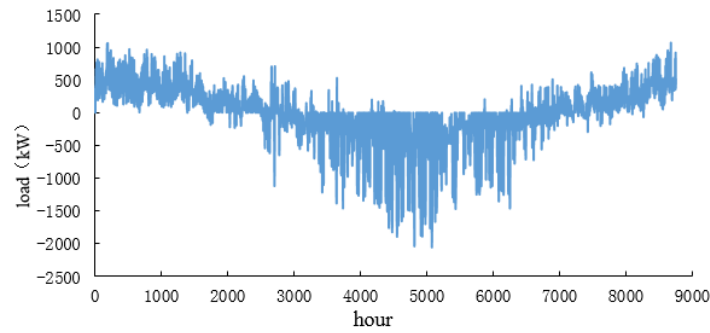


Fig. 3. Schematic diagram of hourly load distribution

3. Introduction of GSHP system scheme

Office building is next to the school's South Square, the stadium and leisure green space. So, the area for the boreholes are very abundant. The design of GSHP system need carefully compare the system energy efficiency and economic conditions. Two options are proposed in this paper. The borehole depth is 100 m in Scheme A, the number of borehole is 350, the space distance of it is 5 m. The same energy storage volume is set in Scheme B, but the borehole depth is adjusted to 50 m, so the number is 700. The space distance of borehole is the same with Scheme A. For the two schemes, the load demands of the building are the same, the building heating and air conditioning systems are the same, so the pumps used to supply water to the building is exactly the same. The parameters of the heat pump are also the same. The undisturbed ground temperature is 19°C , the effective thermal conductivity is 1.38W/m.K , the heat capacity is $1925\text{kJ/m}^3.\text{K}$. The water flow of each borehole pipe is set to the same in both scheme. So, the total flow and head of pumps for the borehole system are different. The flow increased and the head decreased in Scheme B compared whit Scheme A. The parameters of different option are shown in Table 1.

Table 1. Parameters of two options

Equipment	Number of units	Parameters	Scheme A	Scheme B
GSHP unit	2	Heating capacity (kW)	1128	1128
		Input power in heating (kW)	208	208
		Cooling capacity (kW)	1078	1078

		Input power in cooling (kW)	192	192
		Flow (m ³ /h)	200	200
Pump for building	2	Head (m H ₂ O)	26	26
		Input power (kW)	22	22
		Flow (m ³ /h)	270	540
Pump for borehole	2	Head (m H ₂ O)	38	28
		Input power (kW)	55	55
Borehole thermal exchanger		Borehole depth (m)	100	50
		Number of borehole	350	700
		Space distance (m)	5	5

4. Simulation and analysis

4.1. Simulation model

In this paper, Transient System Simulation Program (TRNSYS) is used to simulate the GSHP system. TRNSYS is a modular dynamic simulation software, modular is that all of the system by some small system components. A module achieves a given function as long as the transfer of different functions of the module. A system can be simulated by calling the modules and input the corresponding parameters. The idea of modularity allows the user to focus on the input and output relationships between modules and the overall system building, rather than individual modules of the internal algorithm. Users can also use the TRNEdit program to write their own required modules to achieve special functions. TRNSYS software is very powerful and has a wide range of uses. Therefore, TRNSYS is used in this paper for simulation. The simulation model of GSHP system is shown in Figure 4.

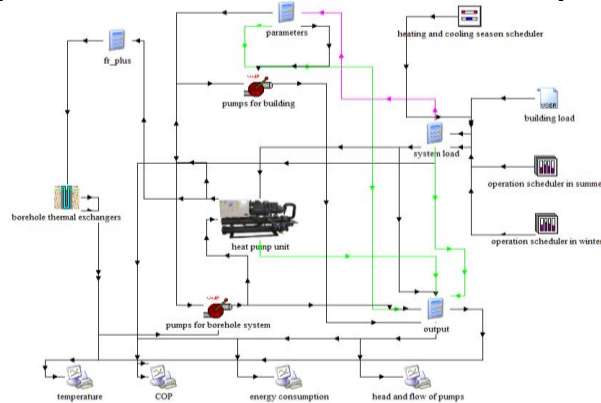


Fig.4. Schematic diagram of GSHP system simulation

4.2. Simulation results analysis

The simulation results of Scheme A are shown in Figure 5 and Figure 6. The output water temperature range of borehole is from 10 °C to 18.2 °C in winter, from 16.8 °C to 27.47 °C in summer. This is benefit to heat pump unit, and the system can efficiently supply energy to the office building. In contrast, the simulation results of Scheme B are shown in Figure 7 and Figure 8. The output water temperature range of borehole is from 9.22 °C to 17.8 °C in winter, from 17.06 °C to 29.23 °C in summer. Soil temperature increases slightly with the increase of depth. So, the output water temperature of borehole is reduced as the depth reduced. Correspondingly, the coefficient of performance (COP) of heat pump unit and the GSHP system are also weakened.

Compared Figure 6 with Figure 8, the energy consumption in Scheme B is larger than Scheme A. In the two schemes, the indoor circulating water pump consumes the same energy. As the output water temperature of borehole is more advantageous in Scheme A, the energy consumption of heat pump unit is lower than the Scheme B. The most significant difference is the energy consumption of pumps for borehole system. As the flow increases, the energy consumption of pumps are increased significantly. The total energy consumption is shown as Table 2.

Compared with Scheme B, the increased percentage of heat pump units' COP in Scheme A is shown in Figure 9, the increased percentage of GSHP system' COP in Scheme A is shown in Figure 10.

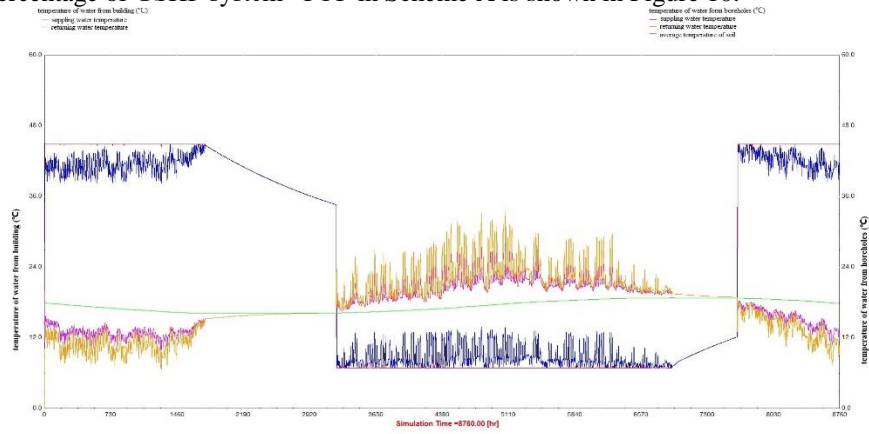


Fig.5. Temperature change of GSHP system in Scheme A

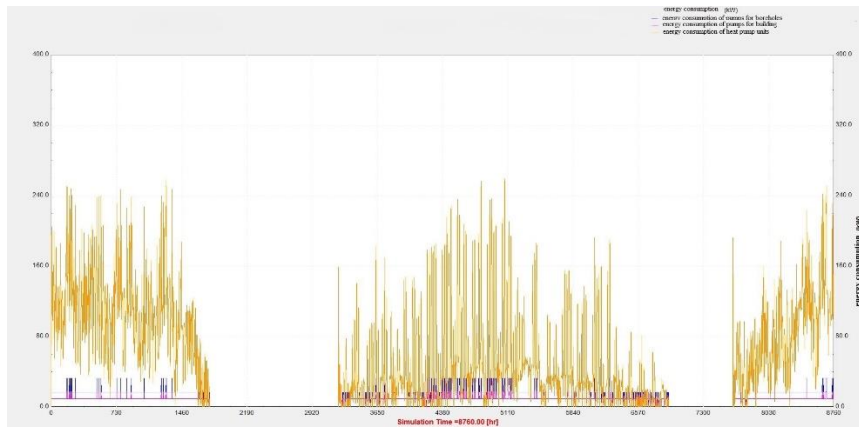


Fig.6. Energy consumption of GSHP system in Scheme A

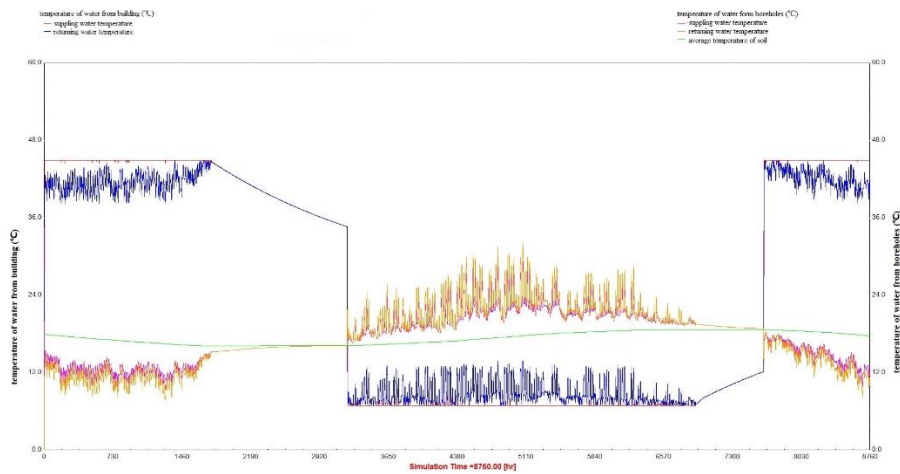


Fig.7. Temperature change of GSHP system in Scheme B

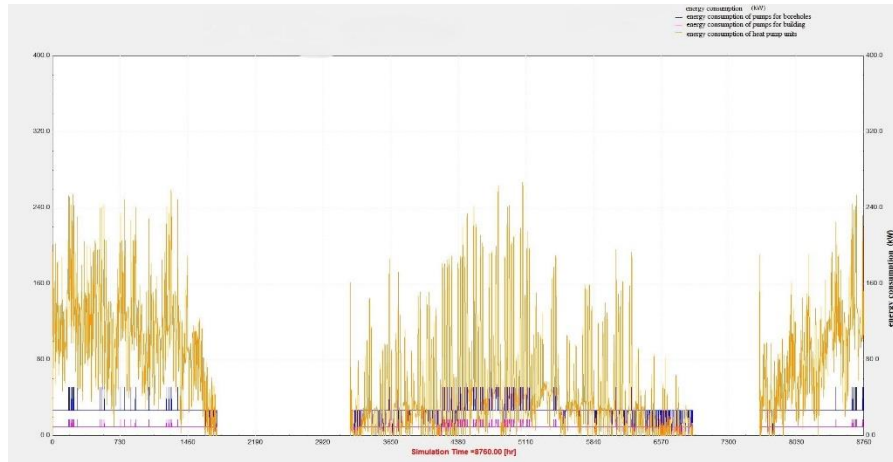


Fig.8. Energy consumption of GSHP system in Scheme B

Table 2. Energy consumption of two options

Options	Annual total energy consumption of GSHP system (kWh)	Annual total energy consumption of heat pump units (kWh)	Annual total energy consumption of pumps for boreholes (kWh)	Annual total energy consumption of pumps for office building (kWh)
Scheme A	602833	432774	109234.9	60824.4
Scheme B	668451.5	436542.5	171084.4	60824.4

It can be seen from Figure 9, in this project, the water temperature from borehole is rising due to increase the drilling depth, so that the energy efficiency ratio of heat pump unit is about 0.11%-1.69% in winter, 0.03%-3.12% in summer.

The improvement of system energy efficiency is the result of energy saving of pumps and heat pump units. Therefore, the improvement rate is greater than the unit. It can be seen from Figure 10, the energy efficiency ratio of GSHP system is about 2.7%-33.8% in winter, 6.77%-35.68% in summer.

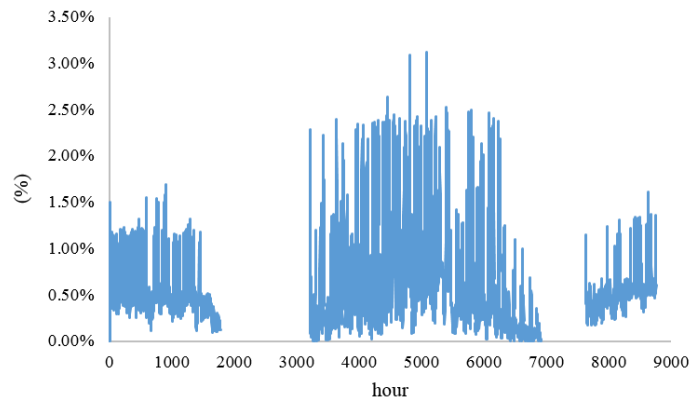


Fig.9. Energy consumption of GSHP system in Scheme B

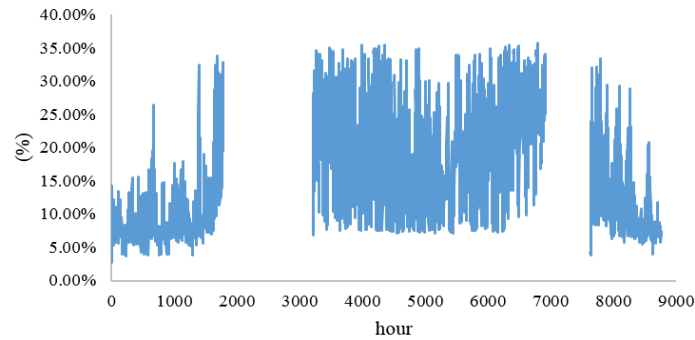


Fig.10. Energy consumption of GSHP system in Scheme B

4.3. Initial cost analysis

The initial cost consists of three parts. The first part is building indoor energy supply system, including the fan coil system and floor radiant system. The second part is the heat pump unit and the pumps. The third part is the borehole systems. The cost of indoor energy supply system and heat pump units for the two scheme are the same. The cost of pump is slightly different. The main difference in cost comes from the borehole system. The cost of drilling is very different in different geological conditions. In this paper, two typical geological conditions are compared to evaluate the investment difference of the system. For the condition A, sand and soil are the mainly content within 120m of drilling depth. In this condition, the drilling operation is facilitated and the construction operation is easy. Therefore, construction and installation costs of boreholes and pipes is not too much when the drilling depth increased from 50m to 100m. For the condition B, sand and clay are the mainly content within 60m of drilling depth. From 60m to 100m, gravel is predominant. The difficulty of drilling gravel layer is greater than the sand layer, drilling costs will be multiplied. Therefore, increasing the drilling depth more than 60m depth, the cost of construction and installation costs of boreholes and pipes will increase a lot. The cost of GSHP system in two geological conditions are shown as Table 3.

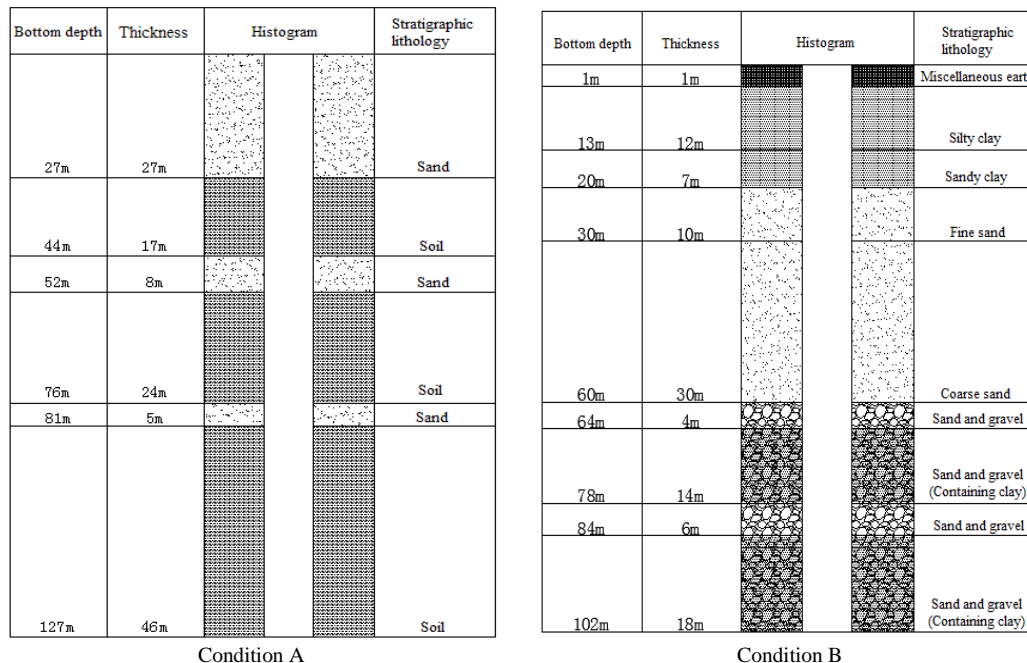


Fig.11. Schematic diagram of two typical geological conditions

Table 3. Initial cost of two typical geological conditions

Options	Geological conditions	Heat pump units and pumps (10 ⁴ RMB)	Borehole system (10 ⁴ RMB)	Indoor energy supply system (10 ⁴ RMB)	Total cost of GSHP system (10 ⁴ RMB)
Scheme A	Condition A	315	690	575	1580
	Condition B	315	937	575	1827
Scheme B	Condition A	315	715	575	1605
	Condition B	315	717	575	1607

In Condition A, Scheme A has the lowest cost, the Scheme B is higher than Scheme A because the length of the connecting pipe is increased. In Condition B, the cost increased dramatically because the cost of borehole system increased.

5. Conclusion

In this paper, through the introduction of a project, the change of COP of GSHP system with 50m and 100m depth is simulated under the same storage volume. From the calculation results, the energy consumption of the water pumps for borehole system has great influence on the COP of the system. In addition, the influence of the drilling depth on the output water temperature of boreholes will also affect the energy efficiency of the heat pump system and the energy efficiency of the system.

In this paper, two typical geological conditions are selected, and the difference of cost in the two conditions is analyzed. The results show that borehole depth has little effect on the cost, only the length of the connecting pipe to increase the part of the cost increase in Condition A when the soil and sand are the main contents. When the borehole depth is increased in Condition B with a thick gravel layer, the cost of the system is significantly increased. Under this condition, it is more competitive to sacrifice part of the energy of system and select 50m depth drilling plan.

Acknowledgements

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