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A Case Study of Shallow Geothermal Heating and Cooling - The Application of Single-well Circulation Heat Exchange Geothermal Energy Acquisition Technology in Haidian Foreign Language School in Beijing and Hebei Campus

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ABSTRACT

Invented by Ever Source Technology Development Co. Ltd., the "single-well circulation heat exchange geothermal energy acquisition technology" is a way to efficiently and safely collect shallow geothermal energy to provide a stable heat source for buildings. This paper introduces the achievements of applying this technology to continuous heating in Beijing Haidian Foreign Language School over the past 20 years. Under the guidance of Academician Wang Jiyang, the case study of the first phase of the project was presented in "Utilization of Shallow Resources-Performance of Direct Use Systems in Beijing" by Shengheng Xu and Ladislaus Rybach at the 2003 annual meeting of Geothermal Resources Council. From 2019, the school expanded its application in the Hebei New Campus project located in Zhangjiakou District of the Beijing Winter Olympic Games to meet the needs of 137000 m^2 buildings in the new campus, including the heating/cooling of various winter sports venues and the provision of domestic hot water throughout the year. The utilization rate of renewable energy has reached more than 60%, with reduced carbon dioxide emissions exceeding 1976 tons per annual. In this project, the "single well circulation heat exchange geothermal energy acquisition technology" is used to obtain renewable shallow geothermal energy without consuming and polluting groundwater to achieve zero carbon emissions in the region.According to the characteristics of decentralized and functional campus buildings, a water-ring heat pump system with centralized energy collection and distributed cold and heat source stations is set to realize system energy conservation further. Seasonal energy storage is used to store heat energy in summer and winter. Heating and cooling have reached a high energy efficiency ratio.

This paper is a continuation of the paper "Utilization of Shallow Resources-Performance of Direct Use Systems in Beijing". The long-term continuous and stable operation has proved that the single well circulation heat exchange geothermal energy acquisition technology is reliable, simple, reproducible and widely adaptable. It is a preferred technical scheme to achieve the goal of "carbon neutralization and carbon peak" in building heating.

1. INTRODUCTION

Shallow geothermal energy refers to the heat energy contained within about 200 meters below the surface, and the temperature is lower than 25 degrees centigrade [1]. Shallow geothermal energy is an important part of the geothermal energy family because of its wide distribution, shallowly buried depth, large reserves, and low development and utilization cost. Shallow geothermal energy can be developed and utilized on a large scale, at low cost and stably, by using advanced single-well circulating heat exchange technology. Combined with heat pump technology to improve its heat energy grade (temperature), so that it becomes an alternative energy source for building heating is a convenient low-carbon path to solve building heating. In 2003 Mr. Xu Shengheng and professor Ladislaus Rybach of Zurich University, taking Beijing Haidian Foreign Language School as an example, jointly published the paper "Utilization of Shallow Resources-Performance of Direct Use Systems in Beijing", for the first time introducing the use of single well-circulating heat exchange geothermal acquisition technology development and utilization of shallow geothermal energy for building heating engineering examples. Adopting single well circulation technology can avoid groundwater recharge difficulties and groundwater resource pollution. Attracted the attention of the conference, and since then, there have been repeated inquiries from the industry. More than 20 years have passed, Haidian Foreign Language School has completed two expansions. Shallow geothermal energy for heating has also developed rapidly in China, and single-well circulation heat transfer technology has been applied to more than 20 million square meters of buildings. This paper takes the study of the latest progress in the Beijing Haidian Foreign Language School heating/cooling system as an example. It introduces its new innovative results and the economic and environmental benefits in response to care from all friends who are interested in the China's shallow geothermal energy utilization and in the single well-circulating heat transfer technology.

2. INTRODUCTION OF SINGLE WELL CIRCULATING HEAT EXCHANGE GEOTHERMAL ENERGY ACQUISITION TECHNOLOGY

Figure 1 is a schematic diagram of a single well-circulating heat exchange geothermal energy acquisition well. The well's upper sealing device and the lower sealing device divide the well pipe into three areas, from top to bottom: the pressurized water return area, the sealing area and the pumping area.The well water is pumped by the submersible pump into the heat pump unit to release heat (heating) or absorptive heat (refrigeration) and then returned to the pressurized backwater area. Through the holes on the casing pipe, the water flows out of the well and conducts heat exchange with the surrounding rock and soil. Then through the holes on the casing pipe, the water returns to the water pumping area. The above pumping area and pressurized backwater area should be in the same water layer to realize the same layer recharge [2]

Single well-circulating heat exchange geothermal energy acquisition well can achieve 100% of the same well and the same layer of recharge, avoiding the difficulties in recharge, which is a common problem in the different well systems. The single well-circulating heat exchange can store the heat obtained from the building in summer, and the heat can be used in winter, realizing the winter and summer balance of the underground temperature field around the acquisition well (Figure 2).

Figure 1: Schematic diagram of single well circulating heat exchange energy acquisition well

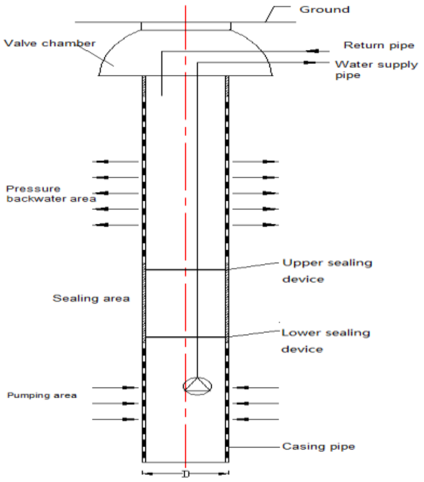
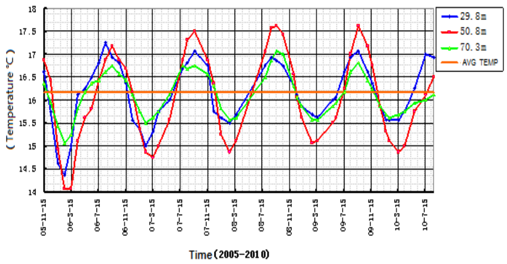


Figure 2: Underground temperature change curve around of an acquisition well in Beijing



Beijing Water Environment Monitoring Center has tracked and monitored the water quality of single well geothermal energy acquisition wells with circulating heat exchange for 16 consecutive years, and analyzed 21 indicators of the water body, confirming that the water quality has not changed significantly except for the water temperature in the output and re-injection water, and the single well geothermal energy acquisition wells with circulating heat exchange have not affected the groundwater quality. Confirm the water quality has no obvious change and single well circulation heat exchange acquisition well did not affect groundwater quality. After expert review, it is confirmed that single well-circulating heat exchange geothermal energy acquisition well technology neither consumes nor pollutes the groundwater. So it is safe for the groundwater quality[3]. It can provide a large-scale, safe, efficient, and stable acquisition of shallow geothermal energy.

3. OVERVIEW OF HAIDIAN FOREIGN LANGUAGE SCHOOL

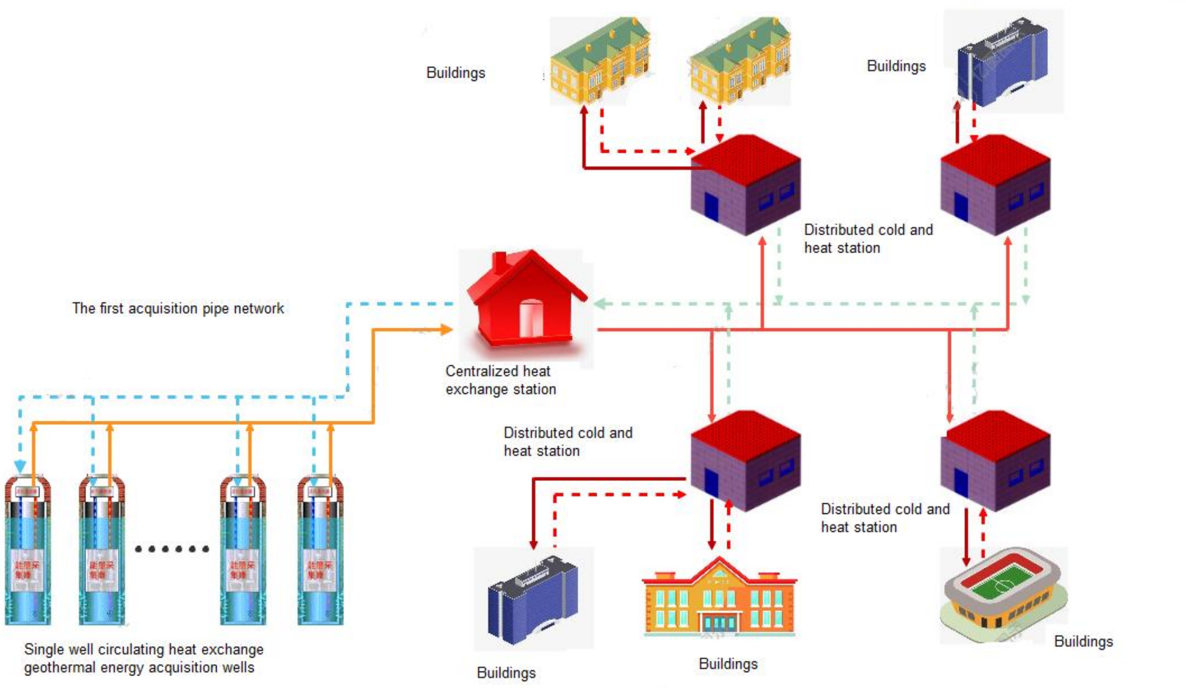
The north campus project of Beijing Haidian Foreign Language School is the first phase of the school, with a total construction area of about 60,000 ㎡. The south campus project of Beijing Haidian Foreign Language School is the second phase of the school, with a total construction area of about 40,000 ㎡. Hebei campus is the third phase of the school. It is located in Zhangjiakou city, the city of the Winter Olympics. Zhangjiakou city is in a cold area. Its outdoor meteorological parameters are shown in Table 1. Construction began in 2019, and all of the projects have completed by 2022. Hebei campus construction area of about 137000 ㎡ is a new 12-year international school with a capacity of 5,000 students, including teaching buildings, office buildings, scientific research centre, art institute, theatre, staff canteen, student apartment, teachers' apartment, indoor and outdoor sports venues, and other 10 buildings, the project building heat load detailed in Table 2. The project is the Beijing Olympic Education Demonstration School for the 2022 Winter Olympic and Paralympic Games and the ice and snow sports base where the General Administration of Sport of China will reserve Chinese national junior team talents for the Olympic Games.

Table 1: Outdoor meteorological parameters of Zhangjiakou city

Station location	northern latitude	40°47′
	east longitude	114°53′
	height(m)	723.9
Atmospheric pressure (mbar)	Winter	938.9
	Summer	924.4
mean annual temperature (℃)		7.8
Outdoor calculation (dry ball) temperature is (℃)	Winter	-15
	Summer	31.6
Outdoor calculation (wet ball) temperature is (℃)		22.3
The hottest monthly average temperature is (℃)		23.2

At present, there are 10 buildings on Hebei Campus. Due to the large campus area, the buildings are scattered, with relatively large surface elevation differences and different use times and frequencies. The shallow geothermal energy distributed cold/heat system is selected for heating /cooling and domestic hot water. The system is composed of multiple single well circulating heat exchange geothermal energy acquisition wells, a shallow geothermal energy centralized heat transfer station, a distributed cold and heat station, and the terminal system in the buildings.

Figure 3. Principle of distributed cold and heat source system



As shown in Figure 3, the multiple single well circulating heat exchange geothermal energy acquisition wells forms an acquisition network. The energy is transferred to the centralized heat exchange station through the first pipe network. By the second pipe network, the heat is distributed to the cold and heat stations, where the temperature will be adjusted for heating or cooling, then through the third pipe network to the buildings, in which the fourth pipe network distributes the heat or cold to rooms.

4. DESIGN OF SHALLOW GEOTHERMAL ENERGY ACQUISITION WELL

According to the formation lithology of the project location, the main parameters of the acquisition well are:117m deep, the open hole 194mm, and the final hole 194mm (Figure 4). The project adopts the DTH and pipe drilling technology. Compared with the impact drilling and well-forming technology in the first phase of the school, the new well-forming technology effectively improves the drilling efficiency and reduces the construction cost. After the acquisition well is formed, the acquisition well is tested. The static water level of the acquisition well is 63m, the dynamic water level is 72m, the water output is 44m³ / h, and the circulating water quantity is 50m³ / h. The water supply temperature of the acquisition well is 15℃ and the backwater temperature is 10℃. Well heating (cold) power formula: N=1.16×Q×| T2-T1 |[2].

The heat transfer power of the acquisition well is: N=1.16×50×| 15-10 | =290kW.

5. ENERGY CONSERVATION AND EMISSION REDUCTION EFFECT

5.1 Operation energy consumption statistics

Table 3 Statistical table of energy consumption data in heating Season 2021-2022

Order number	Name of buildings	Area (㎡)	Cold heat source station system	Annual heating power consumption (ten million kW .h)	Annual power consumption (kW .h /㎡)	Electricity price (RMB Yuan/ kW. h)	Annual heating cost (ten thousand yuan)	Annual square meter heating fee (yuan /㎡)
1	1 # Primary school	19731.65	1 # Station	47.85	24.25	0.4721	22.59	11.45

2	2 # Middle school	27205.45	2 # Station	50.66	18.62	0.4721	23.92	8.79
3	3 # Overseas theater							
4	4 # Comprehensive Sports Center	7797.37	3 # Station	18.02	23.11	0.4721	8.51	10.91
5	Ski hall							
6	5 # Ice and snow center	4558.46	4 # Station	6.96	15.27	0.4721	3.29	7.21
7	6 # International Ministry High School	30456.21	5 # Station	51.02	16.75	0.4721	24.08	7.91
8	7 # International Department of Junior High School	29849.06	6 # Station	45.55	15.26	0.4721	21.51	7.20
9	8 # Kindergarten	17818.28	7 # Station	38.98	21.87	0.4721	18.40	10.33
10	11 # Logistics Office Building							
11	**amount to**	**137416.48**		**259.03**	**19.30**		**122.29**	**9.11**

5.2 Comparison of operation energy consumption in the first, second and third phases of the school

Table 4 Comparison of operation data of geothermal energy heat pump environmental system of Phase 1, Phase II and Phase Ⅲ projects of Haidian Foreign Language School

Comparison table of operation data of geothermal energy heat pump environmental system in Phase I, Phase II and Phase Ⅲ of Haidian Foreign Language School			
order number	**Compare the content**	**Phase I and Phase II (Haidian Campus)**	**Phase Ⅲ (Hebei Campus)**
1	area of structure	100000 ㎡	137416.48 ㎡
2	Heating start time	On October 25	October 15th
3	Heating end time	April 2nd	March 31st

4	Refrigeration start time	May 18th	June 8th
5	Refrigeration end time	September 20th	September 15th
6	Water supply temperature of the acquisition well in heating season	16.5℃	15℃
7	Return temperature of water acquisition well in heating season	13.5℃	10℃
8	Water supply temperature at the end of the heating season	42.2℃	42℃
9	End return temperature of heating season	37.9℃	38℃
10	Total energy consumption in heating season	3792000kW.h	2590300kW.h
11	Energy consumption per square meter in the heating season	37.92kW.h	19.3kW.h
12	Water supply temperature of the acquisition well in the cooling season	28℃	20℃
13	Return water temperature of the recovery well in the cooling season	30.3℃	24℃
14	Water supply temperature at the end of the cooling season	13.8℃	12℃
15	End return temperature of cooling season	15.4℃	15℃
16	Total energy consumption in refrigeration season	1474000kW.h	847900kW.h
17	Energy consumption per square meter during the refrigeration season	14.74kW.h	6.17kW.h
18	Total energy consumption for the year	5266000kW.h	3438200kW.h
19	Average annual energy consumption per square meter	52.66kW.h	25.02kW.h

Compared with Phase I and Phase II of the Haidian Foreign Language School Project, the design of the acquisition well system and the primary and secondary pipe networks are more scientific and reasonable, and the annual energy consumption per square meter is reduced by 52.49%.

5.3 Energy conservation and emission reduction achievements

The total energy consumption of the project in the heating season is 2.5903 million kW.h, equivalent to 318 tons standard coal. Compared with direct electric heating, it can save about 800t standard coal, and the utilization rate of renewable energy reaches more than 60%, which can reduce CO_2 every year Emission by 1976 tons, reducing SO_2 emission by 16 tons and dust emission by 8 tons.

6. MAJOR TECHNOLOGICAL PROGRESS AND INNOVATION

In the past 20 years, the single-well circulating heat exchange shallow geothermal energy heating technology has achieved the following developments and innovations:

1 An acquisition well with heat exchange particles is invented. The well water is pumped out by the submersible pump placed in the bottom pumping area of the casing pipe. After entering the heat pump unit to release or absorb heat, the water unit returns to the upper pressurized return water area of the geothermal energy acquisition well.The water flows downward in the annular space with heat exchange particles to the pumping area [2]. Heat exchange particles are placed in the annular space around the well pipe to improve the geological environment locally and expand the range of high-efficiency heat transfer (Figure 5). The heat exchange particles are solid smooth spheres made of cement. The diameter is about 10mm-100mm with a strength greater than 50 MPa [2].

2 In view of the problem of cross-layer pumping in multi-aquifer geological structures, the multi-water layer geothermal energy acquisition technology has been developed. Two or more well stacking and sealing structures are used to realize the same layer recharge of a multi-aquifer geological structure(Figure 6).

3 In 2012, Ever Source Technology Development Group Co., Ltd. compiled the Technical Code for Single Well of Geothermal Energy Collection with Circulation Heat Exchange DB11 / T 935-2012. Beijing Municipal Water Bureau issued it as a local standard, and it provides the specification for the design and construction of the single well-circulating heat exchange geothermal energy acquisition well.

7. OTHER ENGINEERING CASES

Single-well circulating heat exchange geothermal energy acquisition technology has been well recognized and rapidly promoted since its launch in Beijing in 2001. Now it has been extended to large areas in China except Hong Kong, Macao, Taiwan, and Hainan Province. It has been used in a total of more than 800 projects, with a total construction area of more than 20 million ㎡. Building types include: government offices, commercial office buildings, residential buildings, large shopping malls, stadiums, archives, hospitals, schools, industrial buildings, landscape pools, etc. Table 5 shows some examples of major works in and around Beijing.

8. CONCLUSION

Shallow geothermal energy is the product of both solar energy and geocentric heat. It is a clean and renewable energy source at temperatures below 25℃. With the help of heat pump technology to change its heat energy grade, winter can be used for heating, and summer can be refrigerated. In the field of construction, alternative energy to heating has great development and utilization value.

Single well-circulating heat exchange geothermal energy acquisition technology is original, advanced, and suitable for a variety of geological conditions. It takes the circulating water as the medium to collect the shallow underground heat energy, which can realize the recharge of the groundwater in the same layer without consuming or polluting the groundwater, so it is safe for the groundwater. Now the technology has gone abroad, and some demonstration projects in the United States have been put into operation.

The Hebei Campus of Beijing Haidian Foreign Language School is a new case of using the single-well circulating heat exchange geothermal energy acquisition technology. The system is more reliable and safe than 20 years ago. The energy efficiency ratio of the system has been improved, and the energy conservation and emission reduction effect has been further enhanced. It can be expected that the single well geothermal energy collection technology for circulating heat exchange will help the development and utilization of shallow geothermal energy to further play its advantages and make contributions to the early realization of the dual carbon goal.Reference

[1]Xu Shengheng, Ladislaus Rybach. Utilization of Shallow Resources-Performance of Direct Use Systems in Beijing[J], Annual meeting of Geothermal Resources Council, Mexico (2003)

[2]Local Standard of Beijing city. Technical Code for Single Well of Geothermal Energy Collection with Circulation Heat Exchange [S], Beijing: Beijing municipal administration of quality and technology, December 2012, No. DB11 / T 935-2012(in Chinese).

[3]Wu Qiang, Xu Shengheng. Numerical Simulation and Analysis based on single-well cycle shallow geothermal energy development [J], Engineering Survey, 1, (2015), 45-50.

Table 2: Building heat and cold load table

Order number	Name of buildings	area (㎡)	Design cold load		Design heat load		Design hot water load (kW)	Winter temperature is (℃)		Summer temperature is (℃)	
			Cold indicator (w /㎡)	cooling load (kW)	heating index (w/㎡)	thermal load (kW)		Winter interior design temperature is (℃)	In Winter, the actual indoor temperature is (℃)	Summer interior design temperature is (℃)	Summer the actual indoor temperature is (℃)
1	1 # Primary school	19731.65	65	1282.56	70	1381.22	890	18～24	19-22	22～26	22-24
2	2 # Middle school	19731.65	65	1282.56	70	1381.22	890	18～24	19-22	22～26	22-24
3	3 # Overseas theater	7473.8	65	485.8	75	560.54	0	18～24	19-22	22～26	22-24
4	4 # Comprehensive Sports Center	4470.04	80	357.6	90	402.3	0	18～24	19-22	22～26	22-24
5	Ski hall	3327.33	80	266.19	90	299.46	0	18～24	19-22	22～26	22-24
6	5 # Ice and snow center	4558.46	80	364.68	90	410.26	293	18～24	19-22	22～26	22-24
7	6 # International Ministry High School	30456.21	65	1979.65	70	2131.93	890	18～24	19-22	22～26	22-24
8	7 # International Department of Junior High School	29849.06	65	1940.19	70	2089.43	890	18～24	19-22	22～26	22-24
9	8 # Kindergarten	14253.35	75	1069	80	1140.27	197	18～24	19-22	22～26	22-24
10	11 # Logistics Office Building	3564.93	75	267.37	80	285.19	141	18～24	19-22	22～26	22-24
11	**amount to**	**137416.48**		**9295.59**		**10081.82**	**4191**				

Figure 4 Map of geothermal energy acquisition well

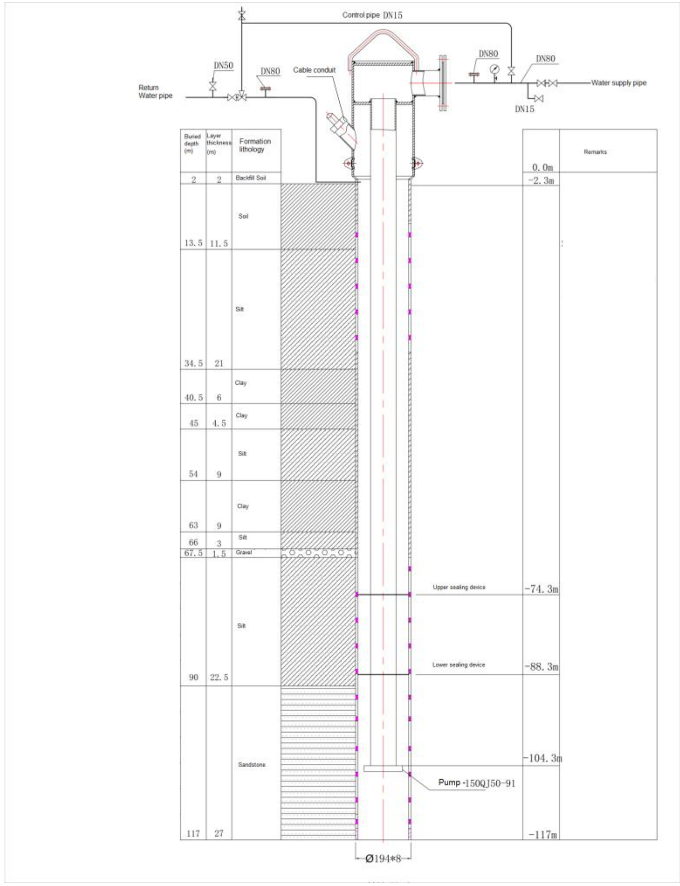


Figure5 Acquisition well structure with heat transfer particles

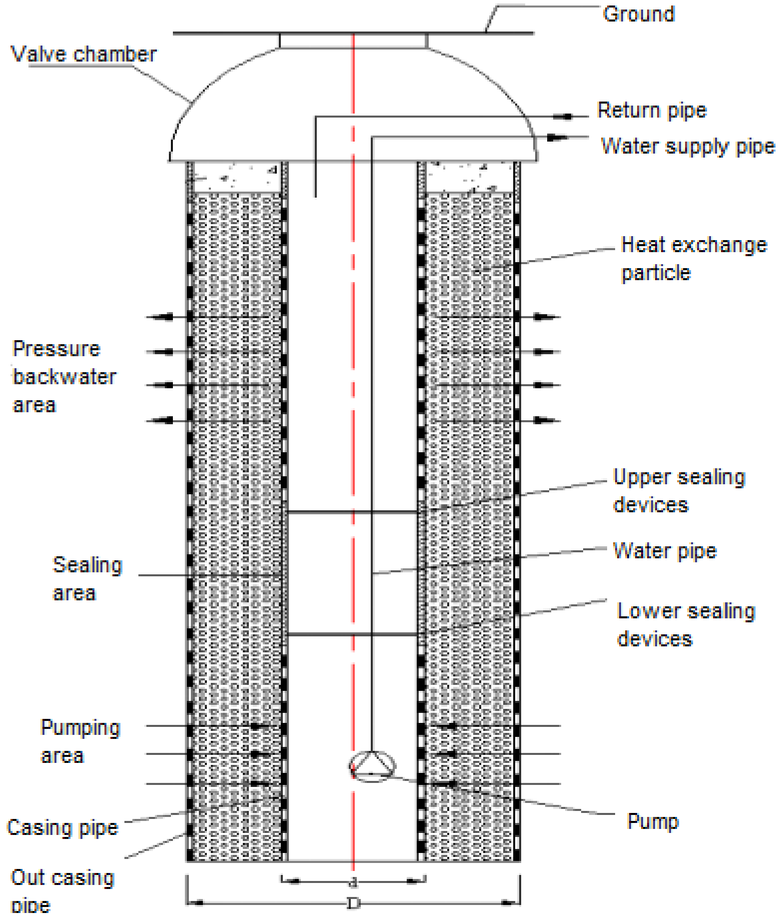


Table 5 Engineering Case Table

Order number	**Name**	**Use**	**Area of structure (m^2)**	**Address**	remarks
1	The All-China Federation of Industry and Commerce office building	office building	50000	Deshengmen West Street, Xicheng District, Beijing	individual building
2	Haidian Foreign Language School	school	62851	Haidian District, Beijing	
3	Hong Kong and Macao Center, National Academy of Governance	office building	43000	Haidian District, Beijing	
4	The Golden Four Seasons Shopping Center	commerce	116000	Xibei Fourth Ring Road, Dian District, Beijing Municipality	individual building
5	Xiongan Civic Service Center	office building	99600	The Xiongan New Area in Hebei Province	
6	National Grand Theater	landscape	30000	West side of the Great Hall of the People	Landscape pool temperature control
7	Haidian District Rural Application Project	house	800000	Haidian District, Beijing	

Figure 6 Multi-aquifer geological structure geothermal energy acquisition well