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Development and Application of a New, Powerful Groundwater Heat Pump System for Space Heating and Cooling

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ABSTRACT

The system is based on original, innovative technology for the development and utilization of shallow ground geothermal energy (heat) – the "Single Well System" technology. It has been invented and developed by Beijing Ever Source Science & Technology Development Co., Ltd to provide buildings with heating & cooling as well as with domestic hot water. Since this technique emerged in 2001, it has attracted the attention of users and government agencies in China.

For the Single Well System, generally, a borehole of about 70-80m depth and with a diameter of 0.5 m is drilled. The prerequisite for geological site condition is to have a shallow aquifer with hydraulic conductivity of 10-3 m/sec or higher. Groundwater with about 12-15°C is pumped from the well and at a rate of 100 m^3/h passes through heat exchangers to release heat to the heat pump. The heat pump provides water with temperature of about 50-55°C to supply fan coilers for space heating whereas the released well water temperature is lowered down to 10°C. This water is then injected into the same well where a special soil heat exchanger takes heat from the surrounding sand and gravel (patent holder: Beijing Ever Source Science & Technology Development Co., Ltd.). By these means, the water temperature returns back to its original temperature of 15°C. The thermal power of a single well is around 0.6 MW. In summertime, "direct cooling" (i.e. with heat pump switched off) is directly provided by the groundwater after heat exchange.

The paper describes the system design and its energy-saving and environmental protection effects by an operating installation in the Beijing area. Further, successfully operating systems in various parts of China are presented, which encompass a wide range of building types and purposes: residential building (single family houses and apartments), office building, hotel, hospital, shopping center, school, waterscape pool (the Chinese National Theatre). The system is also foreseen to serve buildings of the 2008 "Green" Olympics in Beijing. As of August 2004, over 180 such systems are in operation, with a total area of 2'500'000 m^2. The saving of fossil fuel like coal is equivalent to avoiding the emission of 260'000 tons of CO_2, 2'200 tons of SO_2 and 1'600 tons of NO_x. In comparison with direct electrical heating it can reduce power consumption by up to 3/4. The system is now ready for worldwide implementation.

1. INTRODUCTION

The low-temperature geothermal resource, the heat present in the subsurface in the depth range of about 30 to 100 m in the shallow ground, is a ubiquitous energy base. Its utilization is now increasing at high speed worldwide, by means of geothermal heat pumps (Lund et al. 2003). Whereas heat pump-coupled borehole heat exchangers and/or horizontal tubes can be used for heat extraction in dry ground, groundwater heat pumps are suitable in regions with extended shallow aquifers.

In China, and especially in the Beijing area, large regional, shallow aquifers are abundant; the groundwater temperature in the depth range 30 – 100 m is relatively stable around 15°C, without seasonal variations. This resource corresponds in an ideal manner to the endeavors of Chinese authorities to develop indigenous, environmentally friendly and sustainable energy resources.

The Beijing-based company "Beijing Ever Source Science & Technology Development Co., Ltd." has developed a new, powerful groundwater heat pump system for space heating and cooling ("Single Well System of Supplying and Returning Water"). This paper takes the operating installation at the Beijing Haidian Foreign Language School Complex as an example to illustrate how the "Single Well System" works. In this case, the low-temperature geothermal energy from the shallow ground is utilized to provide heat for buildings in winter and to dispose heat into the ground in summer. Domestic hot water is also supplied to the buildings.

Several requirements must be fulfilled for successful and efficient functioning of the Single Well System (Xu and Rybach 2004): presence of an extended aquifer of reasonably high general hydraulic conductivity (on the order of 10^{-3} m/s or higher), relatively shallow water table depth (20 – 30 m), flow velocities around 0.5 – 1 m/day, constant groundwater temperatures (12 – 15 °C). These conditions are widespreadly realized in the Beijing region, where the first Single Well System installations have been established, but later also in many other cities in China, such as Tianjin, Shanghai, Taiyuan, and even Lhasa.

The costs for initial investment and operation to supply heating, cooling, and domestic hot water for buildings are lower than with conventional systems. The environmental benefits (saving of fossil fuel, avoiding of CO_2 emissions) are evident; corresponding data are provided.

2. INSTALLATION DESCRIPTION

The Haidian Foreign Language School Complex is located in the northwestern part of Beijing with a total construction space area of 60,000 m^2. The school complex consists of nine buildings, including Dining Hall, Teaching Building, Gymnasium, Natatorium, etc. The design loads for heating and cooling are shown in Table 1.

The outdoor climate in the Beijing area is characterized by warm summers (July average: +25.8°C) and relatively cold winters (January average: -4.6°C). Mean annual temperature is 11.6 °C.

All buildings in Beijing Haidian Foreign Language School Complex utilize the local groundwater as the heating source in winter. Figure 1 shows the components of the "Single Well System of Supplying and Returning Water". The surface equipment is state-of-the-art and consists of customary components like pumps, valves, heat exchangers, storage tanks, heat pumps, control instrumentation). The innovative, powerful unit of the System is the subsurface component of the system, the"Single Well".

Table 1: Design loads for heating and cooling for the various buildings of the Beijing Haidian Foreign Language School Complex.

No.	Name of Buildings	Area (m^2)	Design Cooling Load		Design Heating Load		Indoor Temp. in Winter (°C)	Indoor Temp. in Summer (°C)
			Cooling Index (W/m^2)	Cooling Load (kW)	Heating Index (W/m^2)	Heating Load (kW)		
1	DH	4'455	80	285	76	338	18-24	22-28
2	B D	6'296	110	554	76	478	18-24	22-28
3	G D	6'296	110	554	76	478	18-24	22-28
4	MS	8'047	85	547	76	611	18-24	22-28
5	PS	8'897	80	567	76	676	18-24	22-28
6	BA	6'009	90	433	76	457	18-24	22-28
7	ST	5'248	70	294	76	399	18-24	22-28
	GY	5'603	65	291	76	426	18-24	26-28
8	NA						26-28	
9	TD	12'000	110	1'056	76	912	18-24	22-28
	Total	**62'851**		**4'581**		**4'775**		

Cooling load calculated with air-conditioning start-up coefficient = 0.8

Abbreviations: Dining Hall (DH), Boy's Dormitory(BD), Girl's Dormitory(GD), Teaching Building for Middle School(MS), Teaching Building for Primary School(PS), Building of Administration(BA), Building of Science & Technology (ST), Gymnasium(GY), Natatorium (swimming pool; NA), Teachers' Dormitory(TD).

Table 2: Annual energy production and electricity consumption, Haidian Foreign Language School Complex, Beijing

No.	Building	Total heating energy (MWh)	Total cooling energy (MWh)	Total heat extracted form ground (MWh)	Total heat injected into ground (MWh)	Total electricity consumption for heating (MWh)	Total electricity consumption for cooling (MWh)
1	DH	544	247	408	185	136	61
2	BD	992	450	744	337	248	112
3	GD	860	390	645	293	215	97
4	MS	836	380	627	285	209	95
5	PS	664	301	498	226	166	75
6	BA	564	256	423	192	141	64
7	ST	340	154	255	115	85	36
	G Y	268	121	201	91	67	30
8	NA	1'204	547	903	410	301	136
9	TD	1'584	720	1'188	540	396	180
Total		**7'856**	**3'566**	**5'892**	**2'674**	**1'964**	**886**

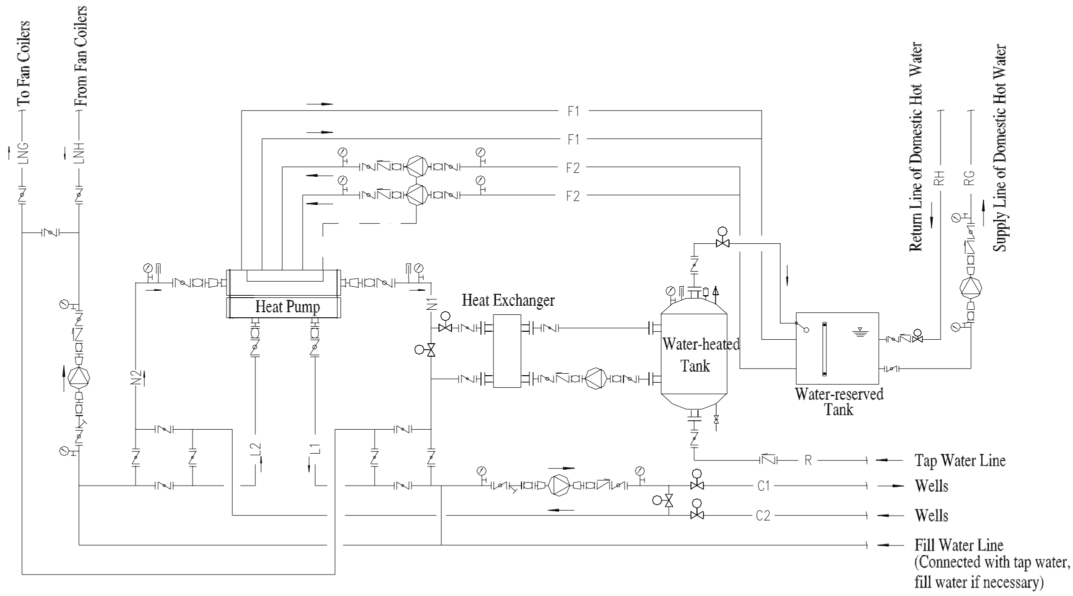

Figure 1: Principle components of the "Single Well System of Supplying and Returning Water"

3. OPERATIONAL PRINCIPLE OF THE "SINGLE WELL" SYSTEM

At the Haidian Foreign Language School nine wells are drilled beside 9 buildings (10m away generally), about 80m deep and with a diameter of 500mm. Groundwater with about 15°C is pumped from the wells through heat exchangers into heat pumps by a submersible pump at a rate of 100 m^3/h per well. The heat pump raises the temperature to 50 °C to supply the fan coilers for space heating. The released water temperature is lowered down to 10 °C; this water is injected into the same well where heat exchange with the surrounding ground takes place through a special metal mesh at the borehole wall (patent holder: Beijing Ever Source Science & Technology Development Co., Ltd), where the water reaches the original 15°C. The thermal capacity of a single well is around 0.8 MW.

Figure 2 shows the structure of the Single Well system. It divides the lower section of well into two parts by clapboard 1: one part is the low pressure (suction, production) space, the other one is the pressurized (return) space. When the production pump is running, water is being sent to heat exchanger at the wellhead, where it releases its heat, then the water is sent back to the return space. The water extracts the heat from the ground through the wall of the well. The heat collecting process is accomplished through these repeated circling actions. There is no vertical water flow in the well (except in the production/reinjection pipes).

In order to let the water return more smoothly and the heat exchange proceed more effectively, another clapboard 2 is installed to let the water with some pressure between clapboard 1 and 2, then the reinjected water reaches further out and the heat exchange will be more effective. Flowing groundwater can supplement heat to those portions of the ground from which the heat was extracted, thus it can keep a heat balance within the same volume.

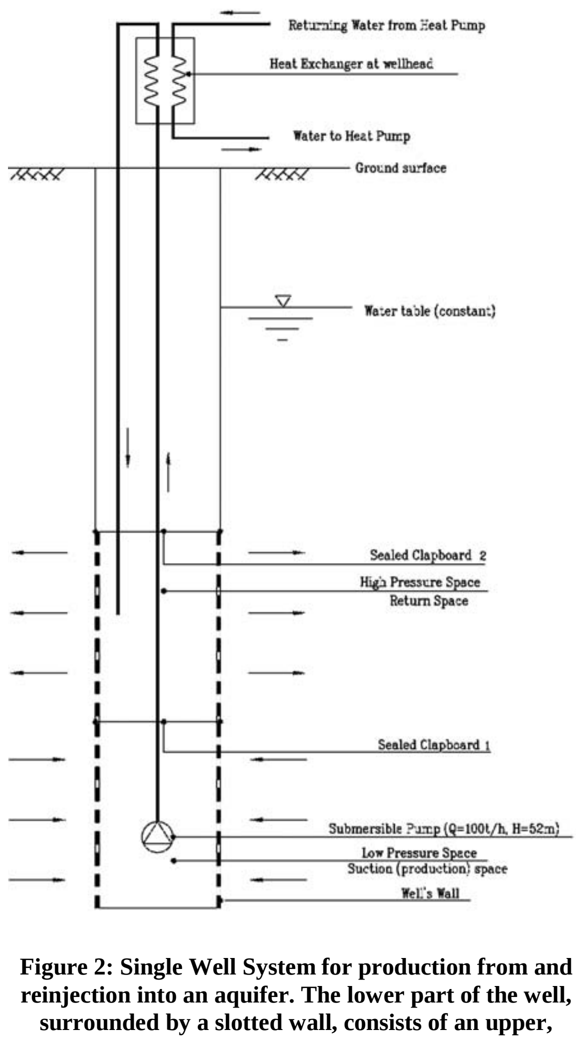

Figure 2: Single Well System for production from and reinjection into an aquifer. The lower part of the well, surrounded by a slotted wall, consists of an upper, pressurized reinjection section and a lower, low-pressure production section.

Since supplying water and returning water is from and to the same well, the above-mentioned technique is called “Single Well System of Supplying and Returning Water”. Comparing with traditional heating techniques, its advantages are as follows:

1. The initial investment is lower; in Beijing, the investment is only 1/4~1/3 of the conventional geothermal heating systems;

2. The groundwater regime is not affected, i.e. the quality and quantity of underground water is not changed;

3. No pollutants are discharged by this process.

4. OPERATIONAL STATUS

The “Single Well System of Supplying and Returning Water” has been in operation since 2001; it works very well up to today. The indoor temperature in winter and in summer meets all the design requirements. The amounts of energy supplied by the system as well as the electricity consumption for the Haidian Foreign Language School complex is given in Table 2.

The operation cost is as low as that of government-regulated heating cost using coal (Xu and Rybach 2003).

The Water Source Monitoring Center of Beijing Municipality has carried out an extended monitoring program, observing the quality of water in these wells in the last three years, with intensified monitoring during the last 9 months. They analyzed 21 index properties of the water quality and identified that none of the indexes had significant changes except for the water temperature. This indicates that “Single Well System of Supplying and Returning Water ” doesn’t affect the quality of groundwater. The groundwater cooling was max. 5 °C without effect on the system performance; the effect diminishes at a horizontal distance of about 10 m from the well.

5. FURTHER SYSTEMS IN OPERATION

The new technology of the “Single Well System of Supplying and Returning Water” has been applied widely since it’s first installation in Beijing. Subsequently it has been adopted even in such remote provinces and areas of China as Ganzi and Tibet. Over 180 projects have been established with a total construction space now exceeding 2’500’000 m^2, including general buildings such as hotels, residential buildings, shopping centers, buildings of administration, schools and gymnasiums, and special buildings such as hospitals, archives and factories, landscape buildings such as China National Theatre. Table 3 lists some main installations in operation.

The groundwater in the shallow subsurface is not only the heat source for heating in winter, but also the cool source for cooling in summer. As the groundwater temperature is far lower in summer than the outdoor air temperature, the cooling efficiency is higher and water is not consumed in contrast to traditional water-evaporating cooling units. In fact, in most areas of China, when outdoor temperature is below 35°C, the indoor temperature can be controlled under 28°C by utilizing the well water directly for cooling without running the heat pump. The average electrical capacity requirement for pumping the cool groundwater is under 2W per m^2.

6. CONCLUSIONS

1. The low-temperature geothermal energy from the shallow ground represents a powerful heat or cold source. Thus it represents an abundant and widespread resource, which can be utilized in a sustainable manner.

2. The “Single Well System of Supplying and Returning Water” is especially well suited to develop and use shallow geothermal resources. It takes groundwater as the medium and provides the technological solution with low initial and running costs.

3. The system discussed in this paper is a closed-circuit system, without emission of any gas, solid and liquid pollutants. Widespread application of this system will certainly upgrade the efficiency of renewable energy utilization and promote environment protection while minimizing the cost of geothermal energy development.

4. The saving of fossil fuel like coal by the described installations in the construction area of 2’500’000 m^2 is equivalent to avoiding the emission of 260’000 tons CO_2, 2’200 tons SO_2 and 1’600 tons NO_x. The system is now ready for worldwide implementation.

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Table 3: Operating installations with various usage in different parts of China. Start of operation: October 2001.

No.	Usage type	Object	Construction Area (m^2)	Location	Note
1	Residential Building	Jintai Apartment Building	14,130	Shijingshan District	
2		Delinyijing Residential Building	71,374	Daxing District	
3		Fuyuan East Villa	64,702	Yizhuang Development Area	
4	Office Building	Office Building of District Government	58,915	Beijing	
5		Second Office Building of District Government	64,000	Beijing	
6		Tibetan Hall	70,295	Lhasa, Tibet	
7	School	Foreign Language School	65,308	Beijing	
8	Hotel	Xingming Lake Holiday Inn	14,000	Daxing District	
9		Songlu Hotel	12,000	Beijing	
10	Commerce	Shopping Center	118,000	Beijing	
11	Hospital	Senior Citizen Hospital	24,971	Beijing	
12	Nursery School & Elder People's Home	Sijiqing Nursery School	6,963	Beijing	
13		Sijiqing Elder People's Home	18,429	Beijing	
14	Bank	Beijing Rural Credit Cooperatives	3,600	Beijing	
15	Archive	Archive Hall	13,066	Beijing	
16	Exhibition	Exhibition Center	10,000	Beijing	
17	Gymnasium	Donggaodi Cultural Center	7,418	Fengtai District	
18	Factory	Jiuzhi Company	9,200	Langfang City	
19	Utilization of Sewerage's and Heat Energy	Changping Sewerage Plant	4,497	Changping District	
20	Landscape	China National Theatre	35,000	Tiananmen Square	Pool Water Temperature Control
21	Special Usage	Huangzhuang Petrol Station	750	Beijing	