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Innovative Groundwater Heat Pump System for Space Heating and Cooling in USA and China

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ABSTRACT

A groundwater heat pump system based on original, innovative technology for the development and utilization of shallow ground water – the "Single Well System" (HYY SWS) is presented. It was developed by the Beijing Ever Source Science and Technology Development Co., Ltd (HYY) to provide buildings with heating and cooling, as well as with domestic hot water. The system characteristics and operational experience has been reported at conferences including WGC2005 and Renewable Energy 2006. So far, the HYY SWS has mainly been installed in China, with one system operating in Mongolia. In 2008, the first SWS was designed and implemented in the USA. It is located in Baker City, Oregon and is designed to supply heating and cooling to a Behlen Manufacturing Co. factory building (1,115 m^2). The system is now in regular operation.

SWS systems were installed for several of the 2008 Summer Olympic Facilities in Beijing: Olympic Village National Gymnasium (80,000 m^2), Athlete Mansion Hotel and Scientific Research Building (64,382 m^2), Tennis Center (26,541 m^2), Hockey Training Facility (11,851 m^2), and Bicycle Training Facility (6,049 m^2). All operate satisfactorily.

1. INTRODUCTION

The Beijing-based company "Beijing Ever Source Science and Technology Development Co., Ltd." (HYY) originally developed the new, powerful groundwater heat pump system ("HYY Single Well System (SWS) of Supplying and Returning Water") for the Beijing area in China. The new technology developed by HYY uses groundwater to provide heating for buildings in winter and cooling in summer. The powerful system operates at 600 kWth capacity with a single well of about 50 – 100 m depth. Domestic hot water is also supplied. The system works in a sustainable manner with a high efficiency and provides cooling without evaporation (Xu and Rybach 2003). The hydrogeological prerequisites and environmental and economic benefits were compiled by Xu and Rybach (2004), along with monitoring results to prove that operating systems have no effect on groundwater properties. In this paper, the HYY SWS operational principle is summarized, its high efficiency is documented, and examples of applications from China and the USA are presented.

2. THE HYY SINGLE WELL SYSTEM

The HYY SWS uses "state-of-the-art surface" equipment, which consists of customary components like pumps, valves, heat exchangers, storage tanks, heat pumps, and control instrumentation. The innovative, basic, and powerful unit of the SWS is its subsurface component, the "Single Well". Unlike traditional groundwater heat pump systems, in which two wells are used (one for pumping groundwater out and the other to dispose of cooled water), the HYY SWS uses one specially designed well for production and reinjection.

A borehole with a depth of about 70-80 m and a diameter of 0.5 m is drilled for HYY Single Well Systems. The necessary local geological site condition is to have a shallow aquifer with a hydraulic conductivity of 10^{-3} m/sec or higher. A schematic diagram of the HYY SWS is shown in Figure 1. Groundwater at a temperature of about 10 – 15°C is pumped from the well (lower, water production space) at a flow rate of about 50-100 m^3/h and passes through a wellhead heat exchanger, where the return water from the heat pump receives heat from the groundwater. The heat pump supplies water at a temperature of about 50 – 55°C to the fan coils for space heating, and the temperature of the water reinjected into the well is lowered to about 5 – 10 °C. The water then flows to the upper return space of the well in a return pipe. Due to the blocking functions of clapboards 1 and 2, this water cannot directly enter the lower part of the well (low pressure section) but exits the well through the meshes in the slotted well wall (patent holder: HYY) and takes heat from the surrounding sand and gravel. This allows the water to return to its original temperature of 10 – 15°C underground in the vicinity of the well. This water then flows back into the production (low pressure) space of the well. The maximum thermal power of a single well is about 0.6 MWth. In the summertime, "direct cooling" (i.e. with heat pump switched off) is provided by the groundwater after heat exchange.

3. EFFICIENCY COMPARISON WITH OTHER GEOTHERMAL DIRECT USAGE TYPES

Regardless of its size, the HYY Single Well System (SWS) provides a very substantial geothermal supply capacity (several hundreds of kW). A comparison with other similar usage types (conventional groundwater heat pumps, borehole heat exchangers, standing column wells, boreholes into deep aquifers) demonstrated the great efficiency of the HYY SWS. For this comparison, the specific thermal power capacity (W/m of borehole length) was calculated. The HYY SWS had the highest value by far, clearly demonstrating its superiority. The thermal capacity of the typical HYY SWS was 7500 W/m, compared to 1800 W/m for wells in deep aquifers, 1000 W/m for typical conventional groundwater heat pumps, 532 W/m for standing column wells (USA average), and 50 W/m for borehole heat exchanger–coupled heat pumps with average boreholes (details in Xu and Rybach 2006). In addition to

the high specific capacity of this system, the relatively small drilling depth required is an important advantage. Drilling deeper for the installation of other systems (except for the conventional groundwater heat hump system) is more costly and risky.

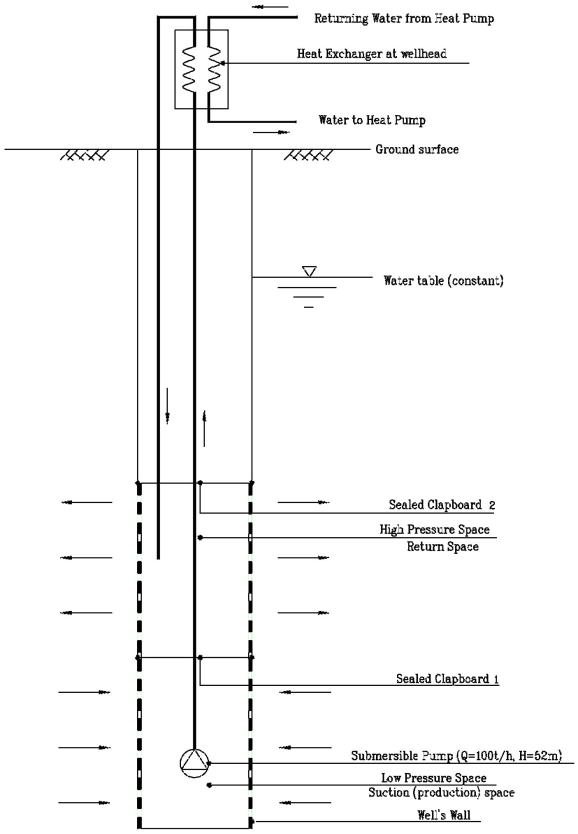

Figure 1: HYY Single Well System (SWS) for production from and reinjection into an aquifer. The lower part of the well, below clapboard 2, surrounded by a slotted wall, consists of an upper pressurized reinjection section between clapboards 1 and 2 and a deeper low-pressure water production section beneath clapboard 1 (From Xu and Rybach, 2005).

4. EXAMPLES OF APPLICATION, OPERATIONAL EXPERIENCE IN CHINA

The HYY SWS can be applied to a wide variety and scale of buildings. Successful applications in various parts of China encompass a correspondingly wide range of building types and purposes: residential buildings (single family houses and apartments), office buildings, hotels, hospitals, factories, shopping centers, and schools. Such examples are described in detail by Xu and Rybach (2005). Operational experience was analyzed, and the positive results were reported by Xu and Rybach (2006).

By the beginning of 2009, the number of successfully operating HYY SWS installations in various parts of China had grown to 399. This included more than 6,644,102 m^2 of total building area and a wide range of building types and purposes:

- residential buildings (2,260,357 m^2)
- administration buildings (2,567,625 m^2)
- hotels (396,793 m^2)
- shopping centers (315,952 m^2)
- schools (454,339 m^2)
- hospitals (62,840 m^2)
- factories (91,243 m^2)
- barracks (177,794 m^2)
- palace buildings (3,499 m^2)
- libraries (13,066 m^2)
- kindergarten and senior homes (35,574 m^2)
- banks (22,721 m^2)
- gymnasiums (140,607 m^2)
- scenery pools (38,354 m^2)
- miscellaneous other (63,338 m^2).

The various utilization possibilities are evident. A special demonstration of versatility is the application of this design to de-ice the 35,000 m^2 "Waterscape" pond in wintertime at the National Center for the Performing Arts in Beijing (Xu et al. 2008).

The widespread application in China there is the beginning of dissemination abroad: HYY SWS installations are in operation in Mongolia and quite recently in USA, as described in Section 5 and Table 1 (Xu et al. 2008). The HYY SWS installations established for the 2008 Beijing Summer Olympic facilities is described in Section 6.

Table 1. Heating and cooling loads, HYY SWS facility for Behlen Manufacturing Co., Baker City, Oregon/USA

Building type	Heating / Cooling Area (m^2)	Heating		Cooling	
		Need (W/m^2)	Load (kW)	Need (W/m^2)	Load (kW)
Office area	613.25	80	49.06	110	67.45
Painting area	501.75	90	45.16	130	65.23
Total	**1115.00**	**-**	**94.22**	**-**	**132.68**

5. THE FIRST HYY SINGLE WELL SYSTEM IN NORTH AMERICA

An HYY SWS installation has been designed and built for the industrial facility of Behlen Manufacturing Co. in Baker City, Oregon/USA. The facility comprises a large single building (1,115 m^2) consisting of offices (613.25 m^2) and a painting area (501.75 m^2). The heating and cooling loads of this system are given in Table 1.

5.1 Hydrogeologic site data

The local groundwater is used as the energy source and store. The hydrogeological conditions at the installation site can be summarized as follows:

- Geologic profile: clays and gravels down to 150 m depth
- Aquifer layer: 89.4 – 123.4 m
- Hydraulic conductivity: 2×10^{-3} m/s
- Flow velocity: 3.5×10^{-5} m/s
- Groundwater temperature: 12°C

The Single Well depth is 91 m, the diameter is 0.152 m, the static water level is at –7 m, and the working water level is at –80 m. A photograph of the HYY SWS well is provided in Figure 2. The 7.5 kW submersible pump operates at a 75 m depth. The water extraction/recharge rate is 9 l/s, and the thermal power is 147 kW. The heat pump ΔT is 3.9°C. Production and operational tests confirm the correct design.

Figure 2: The HYY Single Well during testing. The Behlen Manufacturing Co. building (Baker City, Oregon/SA) to be supplied can be seen in the background.

5.2 The system design

The HYY SWS installation at Behlen Manufacturing Co. in Baker City, Oregon/USA is composed of a single well heat exchange system, heat pump units, water loops, and terminal devices for heating, cooling and hot water distribution. The generally used design for HYY SWS installations is described in detail by Xu and Rybach (2005).

5.3 Licensing experience

The HYY SWS is a novelty in the United States. Correspondingly, the responsible authority (Oregon Water Resources) clearly comments in the license application, that "the request is highly unusual, in that the proposed technology uses a single well for production and injection" (Oregon Water Resources Department, 15 August 2007).

Nevertheless, the authority approved the application by Final Order – Limited License Application LL-1085 (operation license by 19 July 2007) for the "period starting September 30, 2007, and not ending."

6. HYY SINGLE WELL SYSTEMS AT THE 2008 BEIJING OLYMPIC PARK

The HYY Single Well Systems deployed at the 2008 Beijing Olympic Park deserve special attention (Rybach and Xu, 2008). Various buildings and installations are supplied by HYY SWS, as shown in Table 2.

A photograph of the Scientific Research building is provided in Figure 3. The supply and return temperatures during the 2008/2009 heating season by the heat pump in the Athlete Mansion Hotel (27,532 m^2) and Scientific Research Building (36,850 m^2) are given in Tables 3 and 4, respectively.

The observed temperatures and their temporal evolution show similarities, whereas the different electricity consumptions reflect the different building sizes.

Table 2. Facilities of the 2008 Beijing Olympic Park, supplied by HYY SWS installations.

Facility	Area m^2
Olympic Village National Gymnasium	80000
Athlete Mansion Hotel and Scientific Research Building	64382
Tennis Center	26541
Hockey Training Facility in Beijing Lucheng Sports School	11851
Bicycle Training Facility in Beijing Lucheng Sports School	6049
National Great Theatre Waterscape	35000
Water antifreeze facility in a pool near the National Swimming Center	3000

Figure 3: Scientific Research Building at Beijing 2008 Olympics Park

Table 3. Input/output temperatures (in °C) and electricity consumption (in MWh) for the 2008/2009 heating season by the heat pump in the Athlete Mansion Hotel (27,532 m^2), Beijing 2008 Olympic Park.

Heat pump		November	December	January	February	March
Evaporator	Input	14.7	14.8	12.5	13.5	13.1
	Output	10.7	10.0	8.3	8.7	8.4
Condenser	Input	37.6	40.4	41.2	42.3	39.5
	Output	41.7	44.7	44.9	46.5	43.0
Electricity consumption		83.3	214.3	203.8	165.2	79.6

Table 4. Input/output temperatures (in °C) and electricity consumption (in MWh) for the 2008/2009 heating season by the heat pump in the Scientific Research Building (36,850 m^2), Beijing 2008 Olympic Park.

Heat pump		November	December	January	February	March
Evaporator	Input	15.4	13.6	12.3	12.7	13.1
	Output	10.5	9.8	8.4	8.3	8.7
Condenser	Input	39.1	38.6	39.1	39.1	40.7
	Output	43.6	43.0	43.3	43.9	44.5
Electricity consumption		114.6	284.8	330.0	249.8	105.4

7. ENVIRONMENTAL BENEFITS

Geothermal heat pumps (GHP) currently represent the fastest growing branch of geothermal energy utilization (Rybach, 2005). The innovative "Single Well System" (HYY SWS) of Beijing Ever Source Science and Technology Development Co., Ltd (HYY) belongs to this category. Thus, the use of HYY SWS technology also represents an important contribution to the renewable energy field and the mitigation of climate change, as the increasing use of the environmentally friendly geothermal technology enables the displacement of great amounts of fossil fuel use and the reduction of corresponding CO_2 emissions. In the case of the application of GHP systems in building renovation, this results in significant emission reduction. It can be expected that the application of GHP systems, along with other geothermal technologies (especially for power generation), will further benefit future generations.

8. CONCLUSIONS

The HYY SWS uses low-temperature geothermal energy from the shallow ground and thus does not require expensive deep drilling. Groundwater is used as the heat transfer fluid, enabling sustainable operation. The HYY SWS is a closed-circuit system that is free of the emission of any gas, solid or liquid pollutants. The widespread application of this system will displace the use of fossil fuels, upgrade the efficiency of renewable energy utilization, and promote environmental protection, while minimizing the cost of geothermal energy development.

The HYY SWS is superior in efficiency when compared to other types of applications (conventional groundwater heat pumps, borehole heat exchangers, standing column wells, and boreholes into deep aquifers). It provides a highly flexible system to provide space heating, cooling, and domestic hot water to a wide variety of buildings. In fact, HYY SWS are now operating in a wide range of building types and sizes in many parts of China. The operational experiences are excellent and include installations at the Beijing 2008 Olympic Park.

The system is now ready for worldwide implementation. After installing and operating a system in Mongolia in 2006, the first HYY SWS operation in the USA was initiated in Baker City, Oregon in 2007. The latter demonstrates that licensing does not present a problem, even in countries and regions in which this innovative technology has not yet been deployed.

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