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Testing and Analyzing the Use of Low Temperature Geothermal Energy for Heating and Air-conditioning Using Heat Pumps

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ABSTRACT

A water-to-water heat pump, using low temperature geothermal water, was applied to heating and air-conditioning for a hotel. In winter, the heat pump extracted heat from geothermal water between 13~18ºC and provided water between 40~45ºC; in summer, the heat pump discharged heat to geothermal water between 13~16ºC and provided water between 7~10ºC. The economic and environment profits are discussed, and it is indicated that heating and air-conditioning with heat pumps using low temperature geothermal water not only saves basic energy but also protects the environment.

1. INTRODUCTION

In the past years, the direct use of geothermal water developed rapidly, it is mainly used for space heating and supplying hot water, and most of the water is discharged after being used. The temperature of the discharged water usually is high, so the efficiency of geothermal energy utilization is low, it not only wasted geothermal resources, but also caused thermal pollution to the environment. Also with more and more geothermal wells being drilled, it has resulted in ground subsidence; also in order to get hot water at 80ºC, the indicated well depth would be about 1000m, the cost of drilling wells to these depth is prohibitive. In order to resolve and avoid these problems, we need to find new ways of heating.

With the development of the heat pump technique and the environmental concerns over atmospheric pollution, more and more heat pumps are being used for space heating and air conditioning, by extracting heat from or discharging heat to lower temperature source, such as low temperature geothermal water, discharged geothermal water, air or ground. It has good energy efficiency and environmental advantage. Heat pump technology is one energy conservation approach that uses geothermal discharge water or shallow well water as a low temperature heat source and heating network water as a high temperature heat source. Heat pump systems are able to lower the temperature of geothermal discharge water and thus raise the efficiency of geothermal energy and at the same time reduce thermal pollution to the earth surface. Therefore, heat pump systems have been getting world wide attention as means of energy conservation and environmental protection.

In the US, new interest has been shown in the use of geothermal heat pumps to utilize low temperature geothermal sources for space heating. For example, a geothermal heat pump was installed in the Daniel Boone High School in Washington County, resulting in $37000 saving per year[1]. Another geothermal heat pump system was designed to absorb heat from a 30ºC well and supply 52~65ºC temperature water to the Grant County Courthouse central heating system in Ephrata, Washington, resulting in an 80% decrease in energy consumption and an 85% decrease in the Courthouse fuel bill [2].

In Turkey, Department of Mechanical Engineering, a water-to-water geothermal heat pump running on R-22 was designed to utilize disposed geothermal water from geothermal resort centers in Erzurum. The geothermal heat pump uses geothermal water at 35ºC temperature and provide clean water at 45ºC for a floor heating network. The geothermal heat pump heating capacity was around 7.2 kW, and an electric driven hermetic R-22 compressor was used. The overall coefficient of performance was determined as 2.8 [3].

In China, there are many projects using heat pumps for space heating in winter and cooling in summer, which use discharge geothermal water or shallow well water as heat or cold resources. In this paper, an instance of heat pump system is introduced, which uses shallow well water as heat or cold resources, heating and cooling for the building in winter and in summer respectively. This system adopted an injection technique, the water is reinjected to underground after being used.

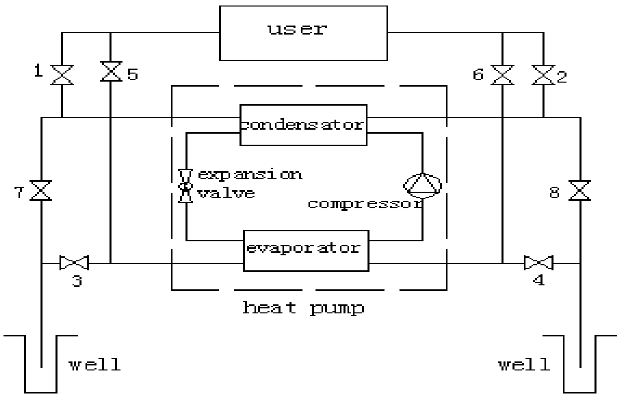
2. SYSTEM DESCRIPTION

The building requires heating in winter and cooling in summer, the total area is about 6000m^2. The heat pump extracts heat or cold directly from the shallow groundwater from a well around 200m. In this system, two wells are drilled, one is as a production well, another is as a reinjection well, and the depths of the two wells are about 200m. The production well and reinjection well are interchanging in winter and summer, i.e. the production well in winter is used as reinjection well in summer, and the reinjection well in winter is used as production well in summer. The system of the heat pump for heating and cooling is shown in Fig. 1.

As shown in Fig1, the heat pump system consists of two water loops and a refrigerant circuit. In the evaporator water loop, heat is extracted from underground water by the evaporator and transferred to the refrigerant, then, the water is reinjected into the reinjection well. In the condenser, the condenser water loop absorbs heat from the condensing refrigerant and delivers it to the building via a fan-coil.

In cooling mode, the evaporator absorbs heat from room via circling water on the user side and transfers it to the refrigerant; in the condenser water loop, heat is discharged into the underwater by condenser. In this mode, underground water is used as the cool resource of the heat pump.

In the refrigerant circuit, refrigerant evaporates by absorbing heat in the evaporator and then enters the hermetic compressor. The refrigerant vapor is compressed in the compressor, and both the temperature and the pressure of the refrigerant steam rise, and then the refrigerant enters the condenser, where it condenses. In the condenser, high temperature and pressure refrigerant vapor discharge heat to the circulating water, and it condenses. After leaving the condenser, the refrigerant goes through the thermostatic expansion valve, where it expands to the evaporation pressure and becomes liquid again.



heating：turn on valve 1, 2, 3, 4 turn off valve 5, 6, 7, 8

cooling：turn on valve 5, 6, 7, 8 turn off valve 1, 2, 3, 4

Figure 1: Schematic Diagram of Heat Pump System

3. THE RUNNING PARAMETER OF THE HEAT PUMP

Running parameters of the heat pump system for heating and cooling were collected during one year. The main data are the temperature of the rooms and the environment, the temperature and flux of the production well and reinjection well. The data were noted every two hours in all the heating and cooling days. Then, the data were processed to obtain the temperature curve of room and environment in winter, the temperature curve of the two wells for heating, the flow curve of the two wells for heating, the temperature curve of room and environment in summer, the temperature curve of two wells for cooling, the flow curve of the two wells for cooling, which are shown in Fig. 2~ Fig. 7.

From Fig. 2 and Fig. 5, we can see that the room's temperature is about 22ºC in winter and 26ºC in summer, Such temperature can make people fell comfortable, so it can satisfy the heating demand.

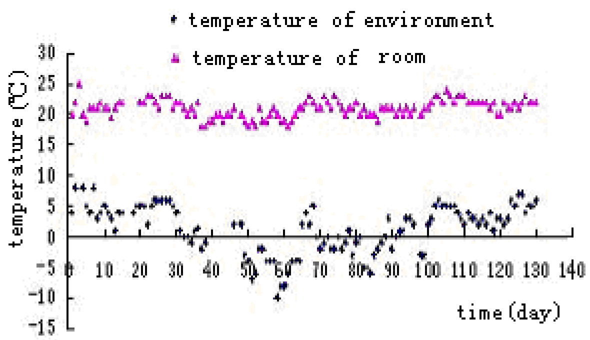


Figure 2: The Temperature Curve of room and environment in Winter

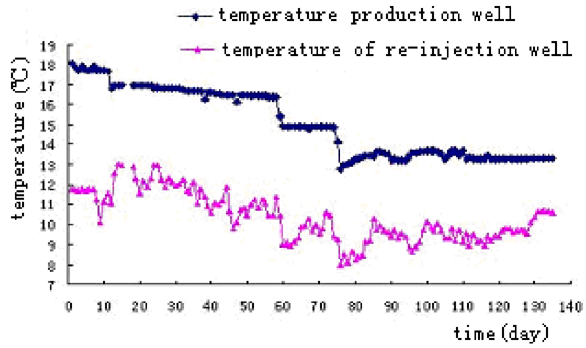


Figure 3: The Temperature Curve of Two Wells for Heating

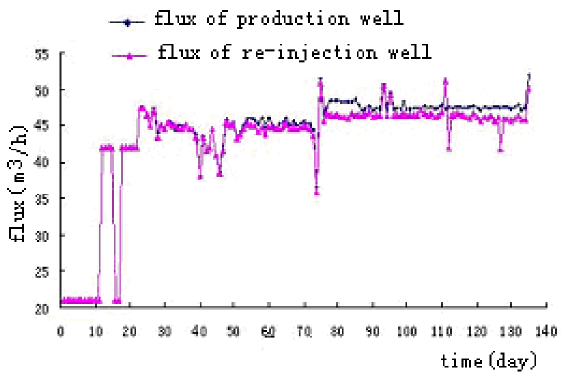


Figure 4: The Flow Curve of Two Wells for Heating

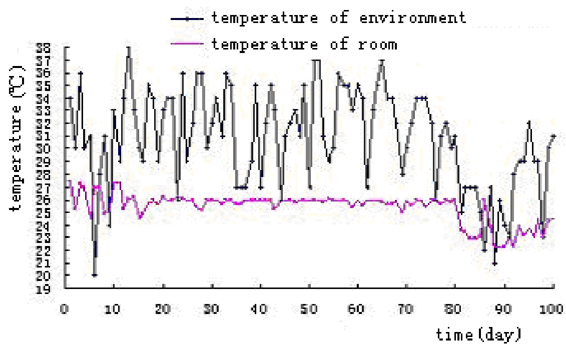


Figure 5: The Temperature Curve of room and environment in Summer

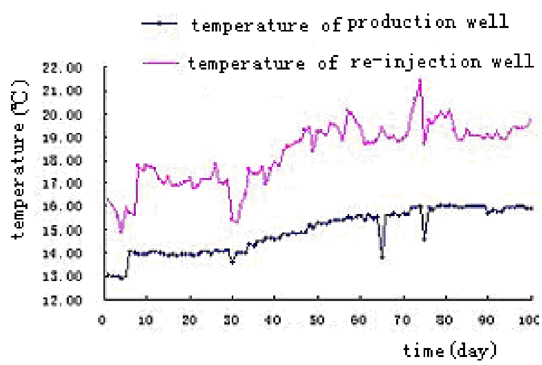


Figure 6: The Temperature Curve of Two Wells for cooling

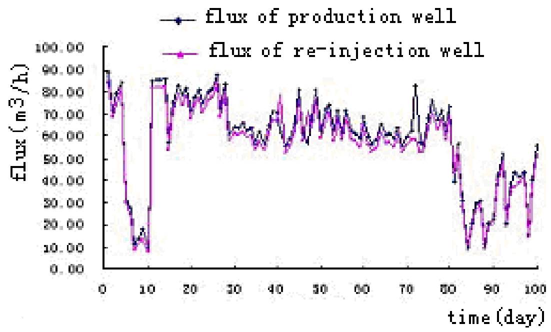


Figure 7: The Flow Curve of Two Wells for cooling

In winter, heat pump extracted heat from the underground water which temperature was about 13~18ºC and provide about 40~45ºC water for space heating. From Fig.3, we can see that the temperature of the production well dropped slowly with the heating time, in the beginning of heating, the temperature of the production well was 18ºC , in the 60th day the temperature rapidly dropped to 16.5ºC and in the 72nd day the temperature rapidly dropped to 12.8ºC, then the temperature rose as the heating time passed, until the heating end the temperature of the production well rose to 13.5ºC. The drop in temperature of the production well is because the effect of reinjection water, the temperature of the reinjection water is lower than the production well. The two wells are close and the permeability of the soil is large, so the lower temperature reinjection water can easily flow into the production well. The total flux of reinjection water is increased, which results in the drop of the temperature of the production well water. In the 60th and 72nd day, the temperature of the production well dropped rapidly because the effect of the environment, the well is shallow, and in the 60th and 72nd day, temperature of the environment dropped suddenly which influenced the temperature of the production well. So we say that the temperature of the well is influenced not only by the flux of the reinjection water, but also by the environment temperature.

In summer, the heat pump extracted heat from the room and discharged heat to the underground water, which caused the temperature of the room dropped. From Fig. 6, we can see that the temperature of the production well rose with the cooling time, in the beginning of the cooling period, the temperature of the production well is 13ºC, then the temperature rose with the increase of the total flux of the reinjection water, until by the end of the cooling period the temperature of the production well rose to 16ºC.

From Fig. 3 and Fig. 6, we can see that the temperature of the well dropped in winter and rose in summer, i.e. the heat pump extracted heat from the underground water in winter and reinjected heat to the underground water in summer.

From Fig. 4 and Fig. 7, we can see that the flux of reinjection was almost equal to the flux of production from the well. This indicates that the geothermal water had almost all been reinjected to the well after the heat pump extracted heat or cold from it, i.e. the heat pump used only the "heat" of the geothermal water and did nott have any effect to the quantity of the underground water, So the heat pump gave no pollution to the geothermal water and attained good environmental effects.

4. ECONOMIC ANALYSIS OF HEAT PUMP SYSTEM

The first investment in the heat pump system was ￥1700 thousand (￥7 is approximately US$1 in 2009), which included ￥320 thousand for drilling wells and ￥1380 thousand for heat pump equipment, pipeline and heat exchanger equipment. Because the system of this heat pump system has double use, heat for the building in winter and cooling in summer, in the economic analysis, half of the first investment is counted into the heating system and another half is counted into the cooling system.

The costs of the heat pump system for heating or cooling includes the energy cost, manage use, equipment maintaining use and the equipment depreciation fee. In the cost of the energy use, this includes the cost of the electricity and geothermal water. In this system, the geothermal water is almost all reinjected to the underground, considered a favorable policy, the geothermal water is free, and so the cost of the energy is only the electricity charge.

The cost and the unit cost of heating or cooling through heat pump using shallow water are shown in Table 1 and Table 2. The comparison of the cost of heating through heat pump and through gas boiler and oil boiler is shown in Table 3. In this calculation, the efficiency of the gas and oil boiler is assumed to be 90%.

From Table 1, we can see that the total cost of heating through heat pump is about ￥152.3 thousand in one year and the unit cost is about ￥24.95 /m^2. If not including the equipment depreciation and maintaining charge, the total heating cost and unit cost is about ￥95 thousand and ￥15.565 /m^2 respectively.

From Table 2, we can see that the total cost of cooling using the heat pump is about ￥98 thousand in one year and the unit cost is about ￥16.1 /m^2. If not including the equipment depreciation and maintaining charge, the total cooling cost and unit cost is about ￥42.1 thousand and ￥6.9 /m^2 respectively.

From Table 3, we can see that the running fee of the heat pump is lower than the gas and oil boiler. This is because the heat pump extracts heat from lower temperature resources at the cost of consuming little high quality electricity, so the efficiency of energy transfer is high. For example, suppose the coefficient of performance (COP) of the heat pump is 4, then if the heat pump consumes 1 energy unit of electricity, we can obtain 4 times as much energy as heat. But a gas or oil boiler consumes fossil fuels, the burning efficiency is lower -- even for the most efficient boiler the burning efficiency cannot be 100% due to heat loss. But at present, the initial capital investment of the heat pump system is much higher than that of the gas and oil boiler, which causes the cost of heating by heat pump to be high.

From the point of view of saving energy and environmental advantage, the heat pump consumes directly only electrical energy, not fossil energy, so it saves fossil energy. Also it brings no pollution to the environment, so it attains good environmental effects. So we say that the heat pump is an energy saving and environment-protecting equipment.

Table 1: cost of heating (￥7 is approximately US$1 in 2009)

	Item	Unit price	Number	Cost
1	Electricity charge (Production well pump Water circulating pump Heat pump Fan-coil Reinjection well pump)	￥0.6/kwh	145113 kwh	￥87 thousand
2	Pay for worker	￥800 /person·month	2	￥8 thousand
3	Depreciation			￥38.2 thousand
4	Maintaining charge	invest×1.8%		￥15.3 thousand
5	Management charge	(1+2+3+4)×2.5%		￥3.7 thousand
6	All cost	1+2+3+4+5		￥152.3 thousand
7	Cost of each sq.m.	(1+2+3+4+5)/area		￥24.95 /m^2
8	Running charge	1+2		￥95 thousand
9	Running charge of each sq.m.	(1+2)/area		￥15.56/m^2

Table 2: cost of cooling in summer (￥7 is approximately US$1 in 2009)

	Item	Unit price	Numerical value	Cost
1	Electricity charge (Production well pump Water circulating pump Heat pump Fan-coil Reinjection well pump)	￥0.6/kwh	59499kwh	￥35.7 thousand
2	Pay for worker	￥800 /man·month	2	￥6.4 thousand
3	Depreciation			￥38.3 thousand
4	Maintaining charge	First invest×1.8%		￥15.3 thousand
5	Management charge	(1+2+3+4)×2.5%		￥2.4 thousand
6	All cost	1+2+3+4+5		￥98 thousand
7	Cost of each sq.m.	(1+2+3+4+5)/area		16.1 元/m^2
8	Running charge	1+2		￥42.1 thousand
9	Running charge of each sq.m.	(1+2)/area		6.9 元/m^2

Table 3: the compare of heating through heat pump and through gas and oil boiler (￥7 is approximately US$1 in 2009)

Name	Gas boiler	Oil boiler	Heat pump
Amount of consuming fuel	48.6×10^3 m^3	45.78×10^3 kg	145113kwh
Unit price of the fuel	￥2.5 /m^3	3.0 元/kg	0.6 元/kwh
Cost of the energy	￥121.5 thousand	￥137.3 thousand	￥87 thousand
Manage cost	￥8 thousand	￥8 thousand	￥8 thousand
Cost of heating	￥129.5 thousand	￥145.3 thousand	￥95 thousand

5. CONCLUSION

In conclusion, the heat pump is an energy saving and environment-protecting equipment, and space heating using a heat pump attains good environmental and economic effects. In these days, with greater emergency of the energy supply and greater severity of impacts to the environment, using heat pumps for heating and cooling of buildings has good prospect.

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