Energy Saving of Water Source Heat Pump System

Using Aquifer Geothermal Hot water to be Auxiliary Heat Source*

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ABSTRACT:

A middle-sized Geo-Heat Gradient Utilization System with heat pumps for Space heating was built up in the Campus of Beijing Polytechnic University since 2000. Geothermal hot water was from the production well with 1600 m deep & temperature of 52 ºC. Heat has been supplied from the aquifer hot water to the space heating system with heat pumps for 2000 ㎡ building area. A Plate Heat Exchanger has been used between the Geo-thermal hot water and the cycled hot water. Cycled water will be supplied to heating system. Heat Pumps which can stand 30-35ºC of Entering Source Water Temperature (ESWT) were installed in system. Fan-coil units with low entering water temperature were installed underneath the windows for low temperature heating. Sensors for measuring the temperature, water flow rate, pressure, power etc have been fixed in the system for technical and economical analysis. Geothermal hot water could be utilized fully until 10–20 ºC then returning to re-injection well. Cooling was supplied in summer by reversed cycle of heat pump. Total Efficiency η and Utilization Factor of Geo-fluid ξ will be used for rating this system . A special test told us the data will be η around 5-7， ξ around 0.8.

KEY WORDS : AQUIFER-GEO-HEAT GRADIENT-UTILIZATION WATER SOURCE HEAT PUMP SPACE HEATING

INTRODUCTION

Beijing is one of the Capital Cities with Geothermal Resources of aquifer hot water in the world. More than 200 deep wells have been drilled in the past 30 years. Since the

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** Prof. Ding, Liang shi, Responsible Person of two Projects

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temperature range of water from aquifer was 40 ºC to 60 ºC generally, most of them was used for bathing, swimming, aquaculture and agriculture until 1999. Geo-fluid with temperature of 60ºC has already used directly for space heating since 1970, but its heat energy was not enough in the periods of peak loads. The tailed geo-fluid with temperature of 35ºC was to be drained off to the drainage system. It also caused some pollution of the drainage system. Also hot water from aquifer of 3800 meters deep with temperature of 88ºC was explored in southern of Beijing in 1999.

A middle-sized Geo-Heat Gradient Utilization System with heat pumps for space heating has been built up in the campus of Beijing Polytechnic University since 2000. Receiving the support of government "Demonstration Engineering of Geothermal Space Heating in Beijing" & the project support from Beijing Municipal Commission of Science and Technology, BJPU will do the research of space heating systems and equipments for fitting such a low-enthalpy energy resources using advanced scientific methods & technology. In the campus of BJPU, re-injection well has been drilled with the geologists for searching the technology. These works will be part of the preparation for the 2008 Olympics Games.

The direct use of geothermal energy for space heating has already developed widely in the world recent years. Most of them are in the temperature range of 80-90ºC. Low enthalpy geo-resource are existed in US (Lunds,W.2000), China, France (Laplaige, P.,2000), Poland (Kepinska, B. 2000) and other countries (Lunds W. 2000). The range of reservoir temperature will be from 30 to 130ºC for Poland. The geo-resources of France are mainly low enthalpy with temperature range of over 50 ºC. All of them will be full of experience in technology and economical comparisons.

DESIGN CONSIDERATION

Plan. The retrofitted building for geo-heat utilization will be the office building of Economics and Management School of BJPU. The retrofitted area for geo-heat will be the offices and laboratories of 2,000 square meters among the total areas. The plan will be shown in Fig.1.

Schemes. The low-enthalpy geo-energy will be utilized with gradient utilization stage by stage from temperature of 52 ºC to the possible low temperature of 11.9ºC. It will be the average annual temperature of Beijing. Several systems will be considered in the very beginning. The possible schemes of systems will be different shown in Fig.2.

Fig.2 (A) shows scheme one. Geo-fluid with temperature of 52℃ was drawing from the production well, flowing through a possible water treatment facility (It could be useless if Geo-fluid re-injection totally), temperature was dropped to 48℃.Then flowing a Plate Heat Exchanger, heat was extracting by the cycled water through the Plate Heat Exchanger, temperature of Geo-fluid was dropped to 13-17℃.Then returning to the re-injection well. The cycled water was heated by Geo-fluid

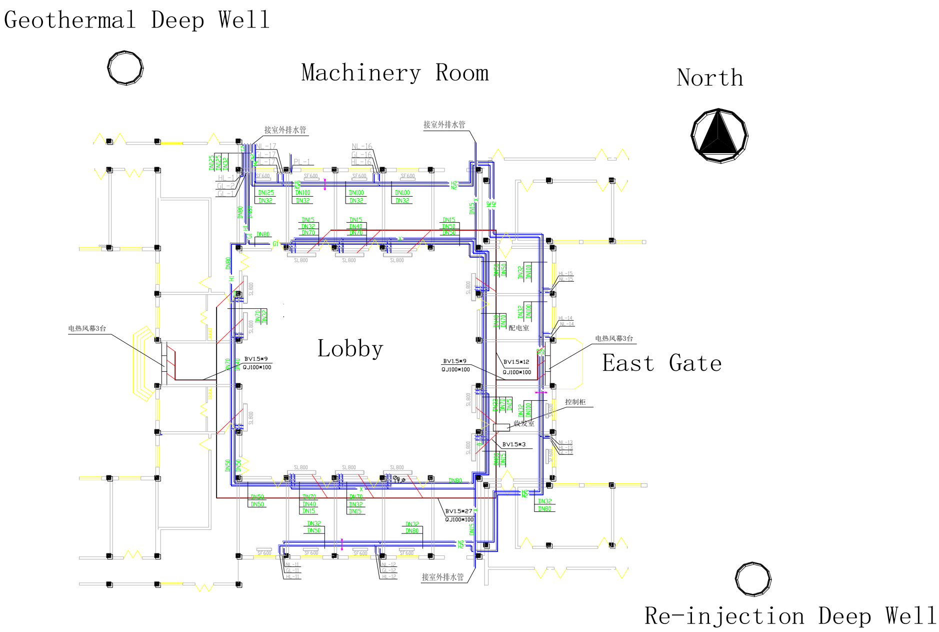
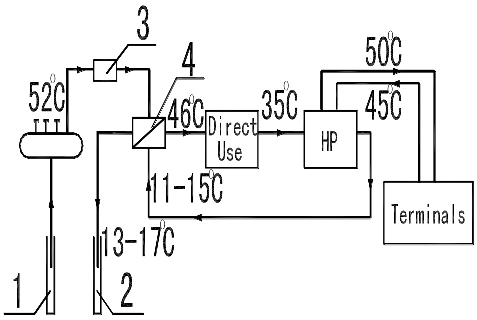
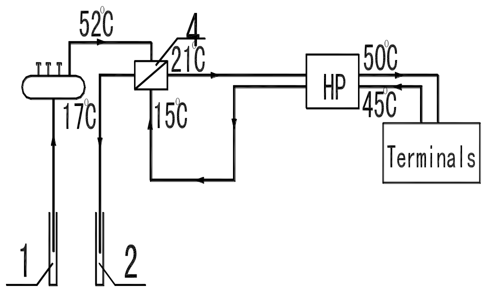


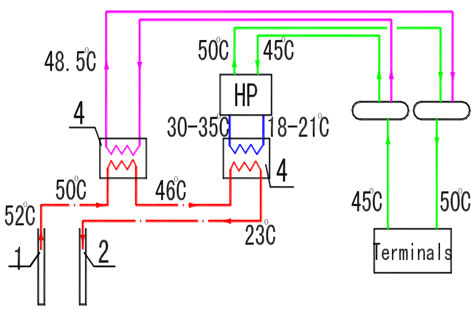
Fig. 1 Plan & Profile of Building for Geothermal Heating



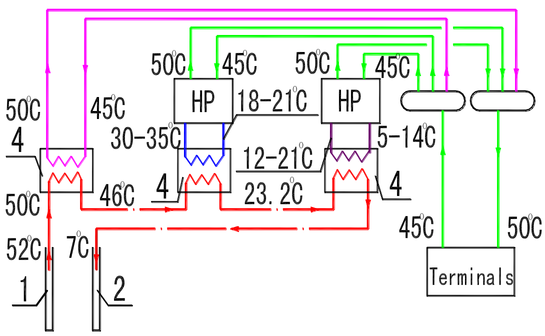
(A) Scheme One



(B) Scheme Two



(C) Scheme Three



(D) Scheme Four

1--- Production Deep Well 2---Re-injection Deep Well 3---Water-Treatment Facility

4---Plate Heat Exchange 5---Shallow Production Well 6-- Shallow re-injection Well

Fig 2 Principle Scheme of geo-gradient utilization systems: Scheme A,B,C,D

until 46℃.Heated cycled water was flowing through Terminal Units of 1st stage &

heat pumps of 2nd stage. Temperature drop △t in 1st stage will be11℃, then entering the evaporators of heat pumps serially, stage by stage, temperature drop △t was 5-6℃ for first heat pump. Final temperature was reaching 11-15℃, returning to Plate Heat Exchanger. Fig.2 (B) shows scheme two. It would be a comparative scheme. Since all the water flow through the heat pumps without direct use, the total efficiency of it must be lower. Scheme One was to be chosen for our test. Scheme of Three & Four have been used in our new Geo-Engineering.

Higher Heating Load. Historically heating load of this building was higher than the others. The lobby is 20 meters high with opened gates. Very large heating load has been caused by infiltration through gates & windows of one layer large glass. So did the worse insulations of walls. It was hard to improve building. Measuring before the retrofitting showed that average temperature of rooms was 13ºC. Average temperature of lobby was 6ºC. People in offices hope to become warm enough in winter and cool enough in summer after retrofitting. Heating load was calculated around 120 W/m^2.

Lower Temperature of Entering Load Water. For improvement of room temperature, it is better to use the Fan-Coil Units with almost same width of the large windows being installed underneath them. The air curtain will be formed from the bottom of windows to the upper through the surface of glass .The higher Temperature of load water will not be required. The energy for operation will be saved.

Heat Pumps. Water-Water Heat Pumps of GSW-120 type were chosen since heat pumps used in this system will be able to stand higher Entering Source Water Temperatures (ESWT). Having ESWT of 35ºC, it will be produced around 3.0 times rejecting heat than that of ESWT of 0 ºC which will be for ground source heat pump in accordance with Standard ARI-330 showed in Fig.5. COP of Heat pump with ESWT of 35ºC will be more than 2 times of that for ground source heat pump if the same heat pump would be used. The curves concerned could be found from company concerned. It shows in Fig.3, 4, 5, 6. Actually we did experimental work earlier using

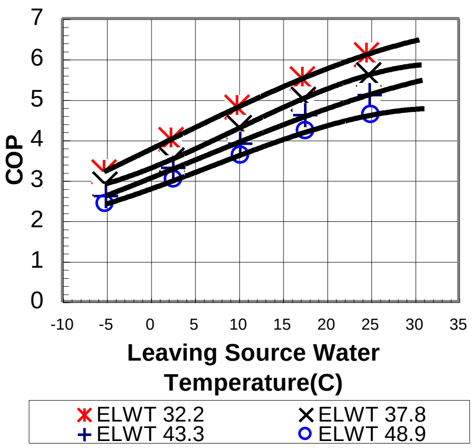


Fig. 3 COP . Vs. LSWT (ºC)

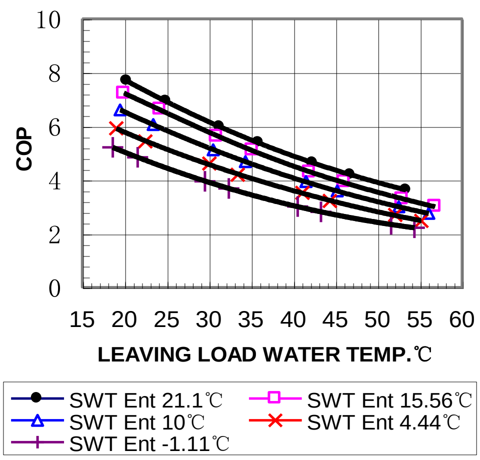
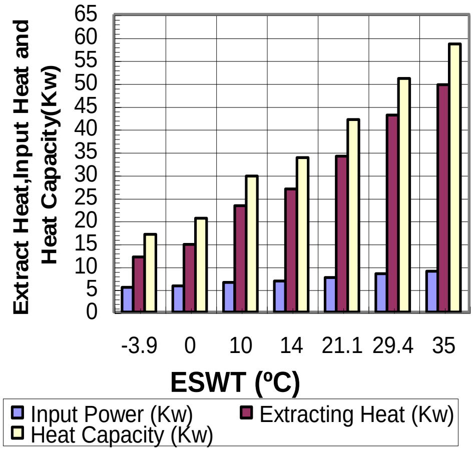


Fig.4 COP . Vs. LLWT

(ºC)



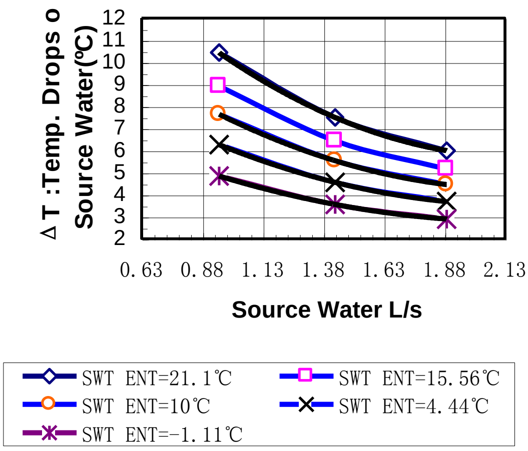


Fig. 5 Extract Heat, Input Power, Heat Capacity (KW) under Source ELWT=32.2(ºC) Load Flow rate 1.69 L/S

Fig. 6 Δ T :Temp. Drops of Source Water (ºC) .Vs. Flow rate of Source Water (L/s)

small-sized experiment system in our Laboratory for choosing suitable heat pump. Ground source heat pump could be able to obtain more COP with other refrigerant.

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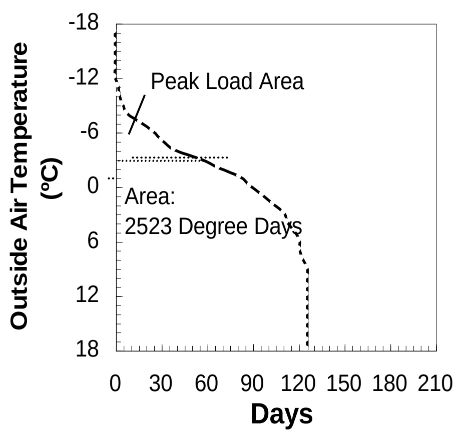
Peak Heating Load Under Consideration: Cooling load will be larger than heating load for this building and other buildings in Beijing. The capacity of heat pumps must be suitable for summer. In winter, some heat pumps could be the equipment for peak load. Lower temperature of tailed geo-fluid could be used. Since the Degree-Days will be 2962 for 182 days of heating and 2523 for 126 days of heating in a standard year of Beijing (Lang, Siwei, 2001). The Degree-Days of peak load will be small. The influence will not be too large for the reservoir. It shows in Fig.7 Fig.8.



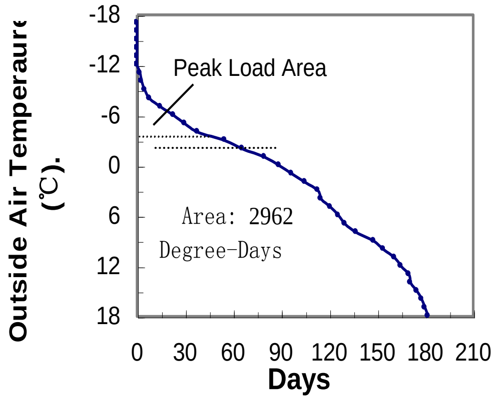
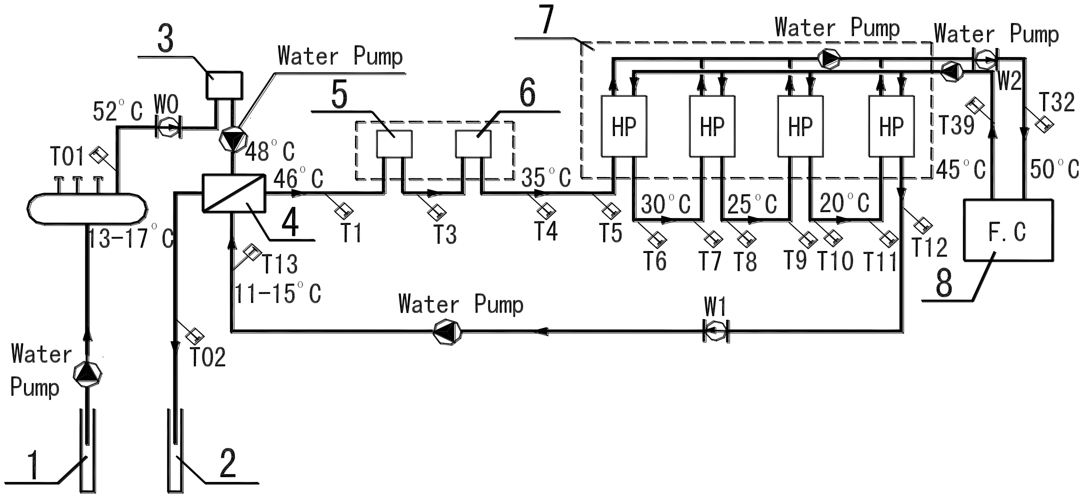


Fig. 7 Degree-Days Curve for 126

Fig. 8 Degree-Days Curve for Six

Days Heating in Beijing **Months Heating in Beijing**

EQUIPMENTS AND INSTRUMENTS UNDER TEST:



1--- Production Deep Well 2---Re-injection Deep Well 3---Water-Treatment Equipment 4---Plate Heat Exchanger 5,6 – Stage of direct use for Geo-heat Utilization 7---Indirect Use Stages of Heat Pump heating 8---Terminals for heating & Cooling

T1, T2, T3, T4, T5, T6, T7, T8, T9,T10, T11, T12, T13, T32, T39 – Sensors of Temperatures

Fig. 9 System & instruments used for test

MEASUREMENT INSTRUMENTS & ACCURACY

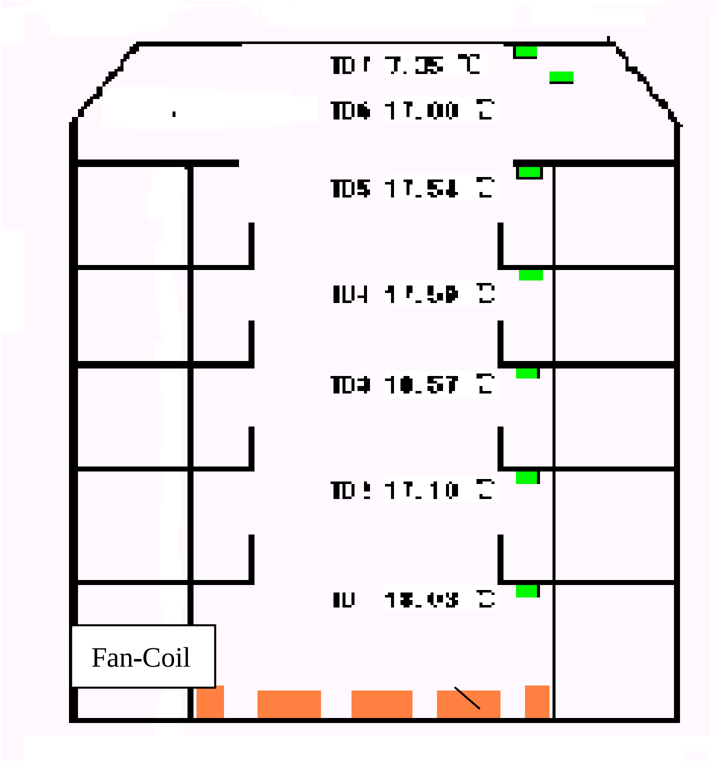
Using sensors to measure parameters concerned will include: sensors for measurement temperature, flow-rate and input power. Sensors of Pt electrical resistance type have been used for measuring temperature of water. The accuracy for measuring temperature of water will be ±1°C. All the instruments have been setting up once per year with Certifications by the Institute of China Measurement Academic. In which the setting up of flow rate sensors were using the method of direct setting. The sensors were being sent to the library with the pipe in which the worm wheel was being inserted. Sensors of temperature were being set up again using high accuracy instruments once per test. Also sensors of remote Kilowatt-hours Meters were being set up again. Uncertainty of instruments is showed in table 1.

Table 1 Uncertainty of Measuring & Calculating Parameters

Basic Parameters					Calculation Parameters		
Temp. of Water	Temp .Diff. of water	Temp. of air	Flow-rate	Power	Heat Capacity		Total Efficiency
T	ΔT	T	W	N	Q	COP	η
(°C)	(°C)	(°C)	(m^3/hr)	(Kw)	(Kw)	1	1
±1%	±2. 6%	±2%	±2%	±2%	±3.8%	±3.8%	±3.8%

OBSERVATIONS OF OPERATING

1 Lobby temperature profile caused by Geo-Heat of Direct Use: Temperature profile caused by Geo-Heat Direct Use is Shown in Fig.10. The lobby is 20m high with glass-top. Temperatures have been increased from 6° C before to 17-18° C now.



Sensors of Temperature From Bottom to Top:

T_{D1}=18.03(° C), T_{D2}=17.10(° C), T_{D3}=18.57(° C), T_{D4}=17.59(° C), T_{D5}= 17.54(° C)

T_{D6}=17.00(° C), T_{D7}= 7.35(° C), RH= 24.63%, Dew Point: Td= -3.64(° C)

Fig.10 Temp. Profile of Lobby caused by Geo-direct Use Stage of Fan-Coil Units

2 Room Temperature and Load temperature: shown in Fig. 11, Fig. 12

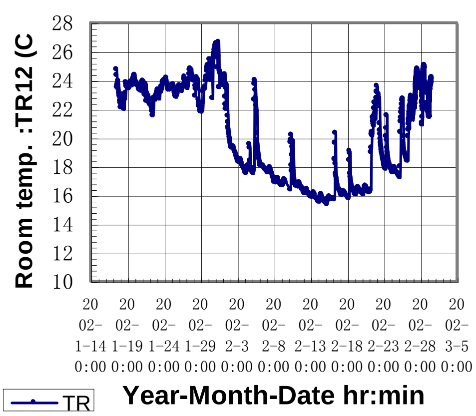


Fig 11 Temperature of Room TR12(℃)

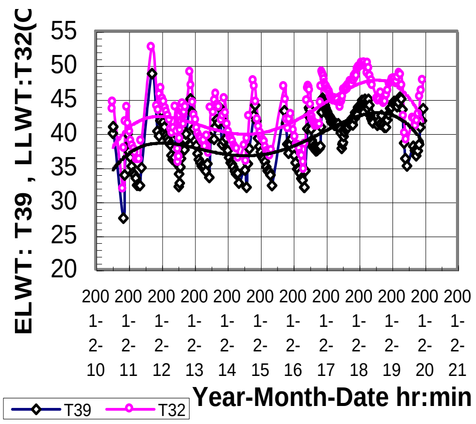
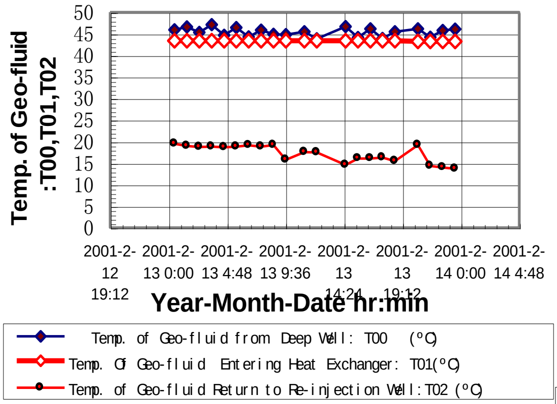


Fig. 12 LLWT & ELWT (℃)

3 Temperature variation of Geo-fluid(° C), Flow Rate (m³/hr) **,shown in Fig.13,14.**



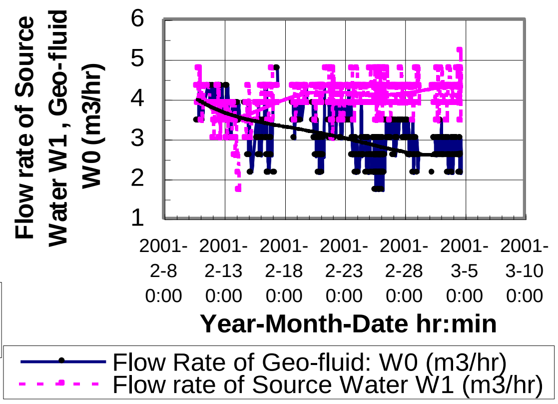


Fig.13 Temperature of Geo-fluid from deep well T_{00}(° C), Entering Plate Heat Exchanger T_{01}(° C) Returning to Re-injection well T_{02}(° C)

Fig. 14 Variation of Flow-Rate of Geo-fluid W_0 & cycled water W_1

SPECIAL TEST FOR SYSTEM RATING

Goal **:** Total Efficiency η & utilization factor ξ of geo-fluid will be used for rating the utilization system

***Mathematics*:**

$$COP = Q_1 / N_1 \quad \text{--(1)}$$
$$\eta = \Sigma Q / \Sigma N \text{-- (2)}$$
$$\xi = (T_{01} - T_{02}) / (T_{01} - T_{ave}) \quad \text{---------------------------------- (3)}$$

where :

$$\Sigma Q = Q_1 + Q_2 \text{..(4)}$$
$$Q_1 = W_2 (T_4 - T_5) - \quad \text{--(5)}$$
$$Q_2 = W_1 (T_1 - T_2) \text{---(6)}$$
$$\Sigma N = N_1 + N_2 + N_3 + N_4 + N_5 + N_6 \text{..(7)}$$

Symbols

COP—Coefficient of Performance

N_1- Input power of Heat Pumps (Kw)

N_2--Input power of Submarine pump (Kw)

N_3--Input power of Geo-fluid Pumps (Kw)

N_4--Input power of source pump (Kw)

N_5--Input power of 1^{st} stage load pumps (Kw)

N_6--Input power of 2^{nd} stage load pumps (Kw)

Q_1--Heat Capacity of Heat pump(Kw)

Q_2-Dissipation Heat of direct use stage (Kw)

ΣQ—Summation of Rejection Heat(Kw)

ΣN—Summation of input Power(Kw)

T_{01}—Temp. of geo-fluid supply (°C)

T_{02}—Temp. of geo-fluid return (°C)

T_1--Temp.of Entering Source Water (°C)

T_2--Tmp.of Leaving Source Water (°C)

T_4—Temp of Load Water (°C)

T_5--Temp of Entering Load Water (°C)

T_{ave}-Average Annual Temp. of dry Bulb (°C)

W_0—Flow rate of Geo-fluid(Kg/S)

W_1- Flow rate of Source Water(Kg/S)

W_2-- Flow rate of Load Water(Kg/S)

ξ --Utilization Factor of Geo-fluid

η —Total efficiency of system

Test Procedures

1 Sensors will be set up again before the test starting. Sensors of temperature & Kilowatt Meters were set up again in this test.

2 Changing or keeping ratio of the flow rate between the Geo-fluid W0 and source water W1, to decrease the temperature of tailed geo-fluid T02.

3 Keep steady for 1-3 hours before test.

4 The time interval for data acquisition: will be 5-10 minutes per record.

5 keep steady for 1-3 hours again for changing a new condition.

6 Calculating total efficiency η and utilization factor ξ from acquisition system.

Results:

1 Total Efficiency η : will reach to 5-7 or more in different case, showed in Fig.15.

(1) Temperature of tail Geo-fluid T_{02}(^{o}C) .

The lower temperature of T_{02} will be, the lower COP and Total Efficiency η will be, as showed in Fig. 15 .

(2) Temperature of tail Geo-fluid T_{02} (^{o}C) will be influenced by the flow rate ratio of geo-fluid to source water W_0/W_1.

(3) The higher the Leaving Load Water Temperature (LLWT) will be, the lower the Total Efficiency η will be.

2 The Utilization Factor of Geo-fluid ξ: ξ will be 0.5—0.9 shown in Fig. 16.

- COP and Total Efficiency η**:** The higher the leaving source water temperature will be, the higher the COP and η will be.
- Utilization factor of geo-fluid ξ: The lower the leaving source water temperature will be, the higher the utilization factor of geo-fluid ξ will be.
- η =7-8， ξ =0.8 must be better.

3 The influence to reservoir must be considered for the rejection temperature.

CONCLUSIONS:

1 Total Efficiency η and **Utilization Factor of Geo-fluid ξ must be one of Rating Criterion.** Advance research has already conducted continuously. More possible system schemes will be under consideration.

2 Different kind of Energy Resource in Comparisons: Aquifer hot water is a special kind of nature energy with heat and mineral materials. It could be utilized in every season directly without heat pumps. It is not suitable to compare for space heating only during the Economic Analysis.

ACKNOWLEDGMENTS

a) Production Wells & Re-injection well were designed and constructed by the Center of Geothermal Resource Research & Exploit of Beijing.

b) System constructed by Company of Installment for Mechanical Equipment & Piping of Beijing and Company of Li-De Wei-tong- ya Auto-Controls.

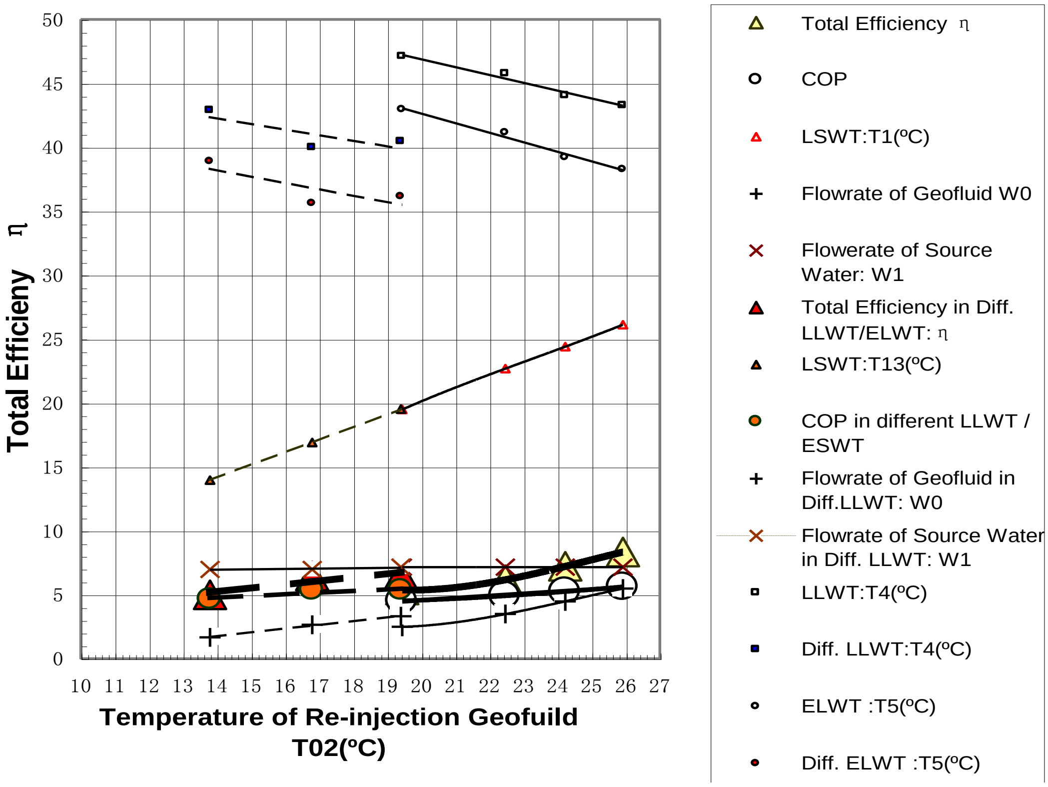


Fig. 15 Total Efficiency η .Vs. Temp. of Re-injection T02 (°C)

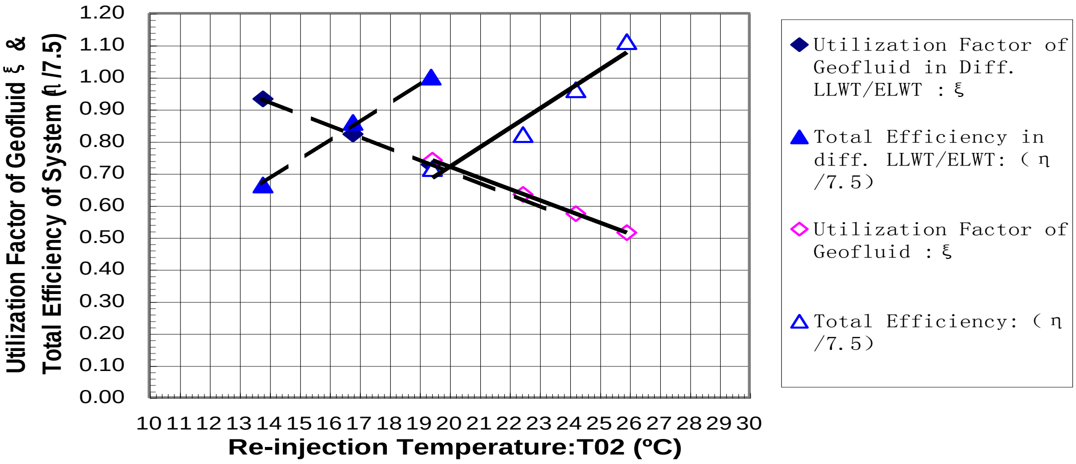


Fig. 16 Utilization Factor of Geo-fluid ξ & Total Efficiency η

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