AIR CONDITIONING SYSTEM WITH GROUNDWATER HEAT PUMP BY AQUIFER THERMAL ENERGY STORAGE (ATES)

Masahiko KATSURAGI, EXECUTIVE DIRECTOR
Yoshito HORINO, MANAGER OF PLANNING DEPT
Kiichi NUMAZAWA, MANAGER OF DESIGN DEPT
JAPAN GROUND WATER DEVELOPMENT CO., LTD, YAMAGATA CITY, YAMAGATA PREF, JAPAN

Abstract : The air-conditioning system with groundwater heat pump using the aquifer thermal energy storage (ATES) is still quite rare domestically in Japan. Japan Groundwater Development., Co Ltd (JGD) started utilizing this system in 1983. It creates less heat emissions, which is believed to be one of the major causes of the heat island effect than conventional systems.
However, we realized that we do not have sufficient data to prove this system is actually environmental load reducing. Therefore we have decided to reevaluate its environmental load and impact by monitoring groundwater consumption, groundwater temperature and amount of electrical energy.
Five wells were situated, three for studying the influence to the ground and groundwater, the other two with the temperature sensor and the water level indicator for the background information. From these results, we have reevaluated the change in ground temperature caused by inter annual operation of this system.

Key Words : heat island, air-conditioning system, groundwater, heat pump, ATES

1 INTRODUCTION

The historical background which led to the birth of the heat pump air-conditioning system using ATES in Japan were as follows;

1) Government's change in its energy policy from its heavy dependence on petroleum to more conservative energy efficient systems after the oil crisis in 1970s.
2) Environmental problems such as the drawdown and the land subsidence caused by the excessive pumping of groundwater for manufacture use and snow melting system in cold region.

To prevent these environmental problems, we started research on artificial recharge for aquifer and came to understand its great potential for heat storage tank. Moreover, JGD has developed snow melting system without sprinkling water which became basic concept for this ATES system. The system started operating in 1983, but by then oil price came down and conventional air-conditioning system had achieved great improvement, the ATES system was scarcely noticed in Japan. Recently, however, global warming and the heat island phenomenon in urban areas have become a pressing problem and we are urged into building more low carbon society. Our technology is now drawing attention increasingly. We would like to demonstrate how much ATES system would be effective to prevent global warming and heat island phenomenon

2 FACILITIES OVERVIEW

2.1 System overview

This is an air-conditioning system which uses heat energy of groundwater (Fig 1).
In winter, groundwater is pumped from new south well, and fed into a heat pump to transfer its heat energy to produce hot water to use heating the office building. After then it is led through the pipes under the parking zone to melt snow, and finally injected back into aquifer through north well to form a cold water zone. In summer, however, groundwater is pumped from north well and fed to the heat pump to produce cold water, then like winter time operation, it is led through the pipes under the parking zone to collect solar energy this time. The heated groundwater is then injected at the new south well to form the warm water zone. Thus, this system utilizes the groundwater heat energy all year round.

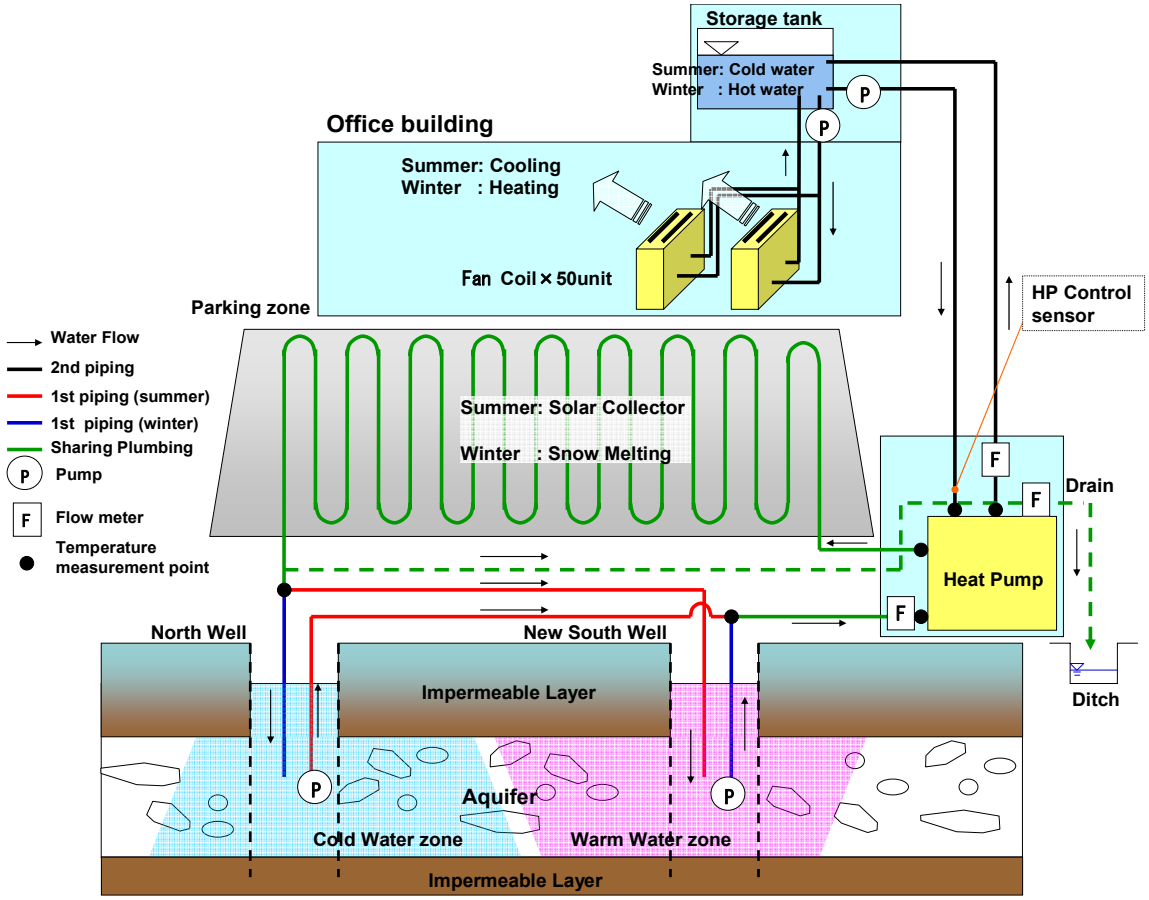


FIgure 1 System overview

2.2 Equipment composition

Table 1 : Main equipments of these facilities

Item		Specification		Remarks
Well	North well	φ350mm×104m depth	7.5kW Submersible pump	Building in 1970
	New South Well	φ150mm×85m depth	7.5kW Submersible pump	Building in 2009
Heat pump		30KW Compressor output	CRH-40G Format	Manufactured 1982
Fan Coil Unit		0.105kW×47 0.045kW×3		Total 50 units
Circulation pump		2.2kW×1	Heat pump to storage tank	

	1.5kW×1	Storage tank to Fan coil unit	
Piping in pavement	800m^2 Construction area	Piping SGP-15A	

2.3 Operation setting

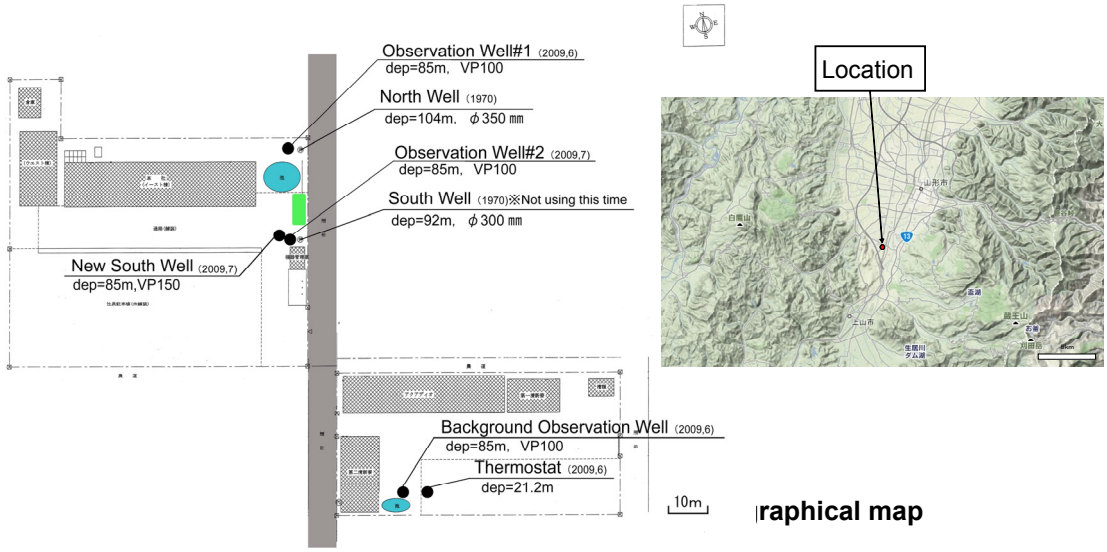
The set value of these facilities are as follows; (Table 2)

Table 2 : Observation period and operation setting

	Summer operation	Winter operation
Observation period	10th August to 30th Sept	2nd December to 31st January
Heat pump	6:20～19:00 (13℃：ON、7℃：OFF)	6:10～20:00 (39℃：ON、44℃：OFF)
Submersible pump	6:20～19:00	24 hour
Secondary circulation pump in 4th floor (2 units)	Control by timer（3:45～21:10）	
Fan Coil unit	Manual：Turn in（3 steps：Low・Med・High / Turn off	
Quantity of pumping	100 L/min from North well	180 L/min from South well
Quantity of injection	100 L/min to south well	100 L/min to North well (Rest of 80 L/min were released)
Quantity of water for secondary circulation	200 L/min	

2.4 Well arrangement

These facilities are located in the southern part of Yamagata basin. Sukawa river flows 1km east side of here. The basement rock is tuff of Cenozoic period Neocene Miocene, and Ryuzan mud flow lodgment of the period pleistocene of 4th of the Cenozoic period distributed. Highest stratum is the alluvium in 4th period Holocene.
Horizontal arrangement of wells are as follows; (Fig 2)



raphical map

3 Observation record

Summer operation started at 9 AM, August 10, 2009 and lasted until September 30. Groundwater was pumped up from the north well and injected at the south well. After a

month of intermission, the winter operation began November 2. This time, groundwater was pumped up from the new south well and injected at the north well. Operation records of this demonstration are as follows; (Fig 3 and Fig 4)

3.1 Temperature record in the piping

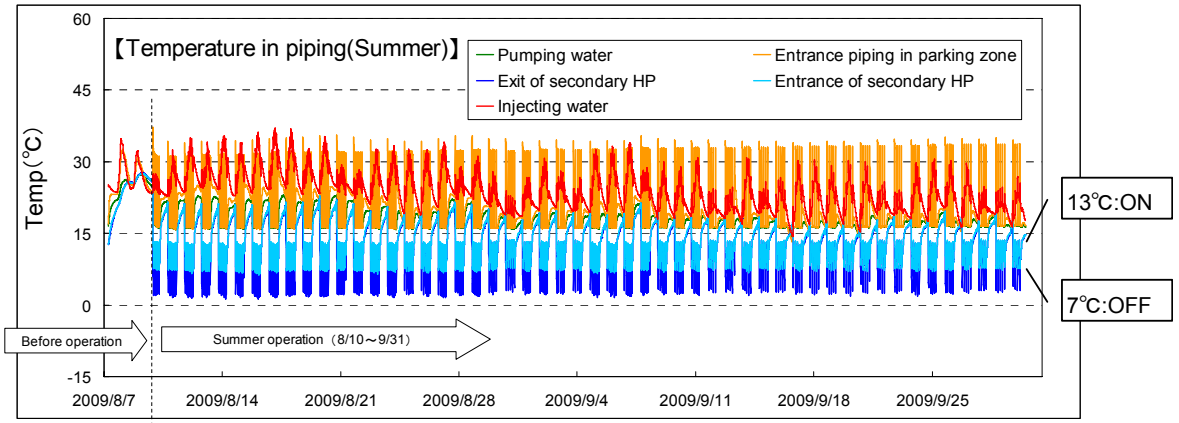


Figure 3 : Records of summer operation

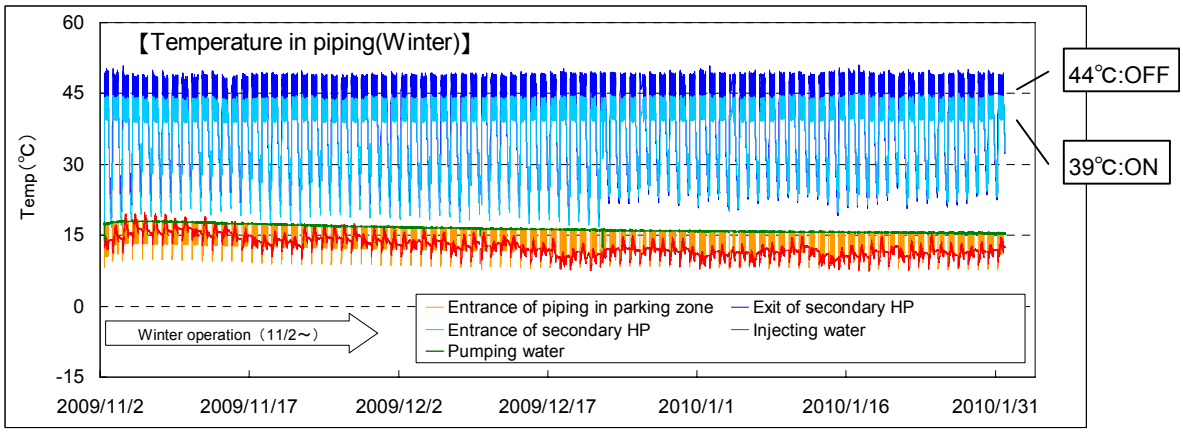


Figure 4 : Records of winter operation

As you can see at Fig 3 and Fig 4, the No.2 heat pump which was used for the office building air-conditioning system operated keeping the setting temperature without a problem in both summer and winter.

The groundwater used in the No.1 heat pump (heat source), exchanged heat energy at the office, then it ran through heat radiation pipe under the pavement to collect solar heat in summer time. The heated water was injected into the aquifer at the new south well.

All through the summer operation, the water temperature before it was piped to heat radiation pipe was almost constantly 33℃, however, when it was injected at the well its temperature was considerably high several times, possibly due to intense summer heat.

The stored heat was utilized during the winter operation. The water was pumped up from the new south well and heat energy was used to warm up the office building and to melt snow.

Nonetheless, the temperature change in the north well (injection well) was confirmed.

The office heating and snow melting demanded greater heat load that it was stored over the summer.

Temperature of the new south well showed 18℃ when the winter operation started but it declined to 15℃ at the end of following January.

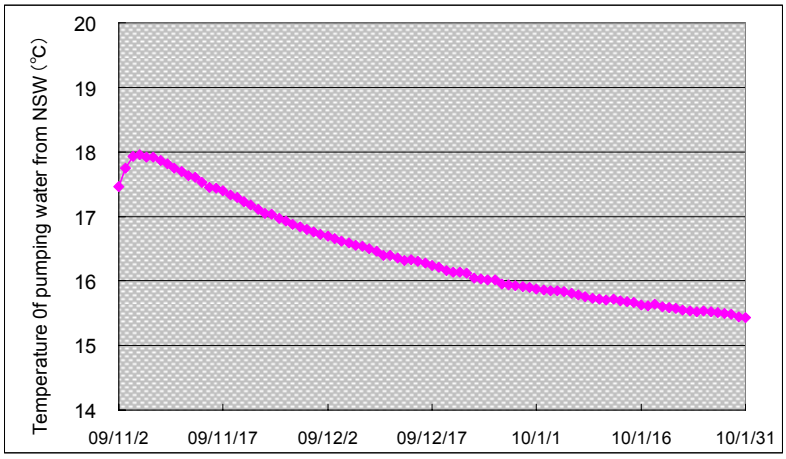


Figure 5 : Temperature of new south well (2008, winter)

3.2 Fluctuation in the office and ambient temperature

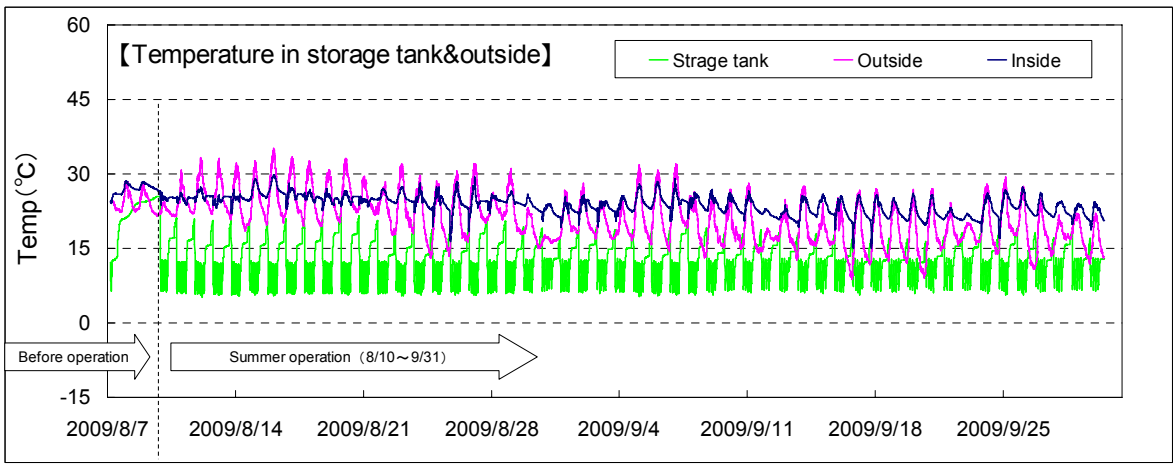


Figure 6 : Records of summer operation

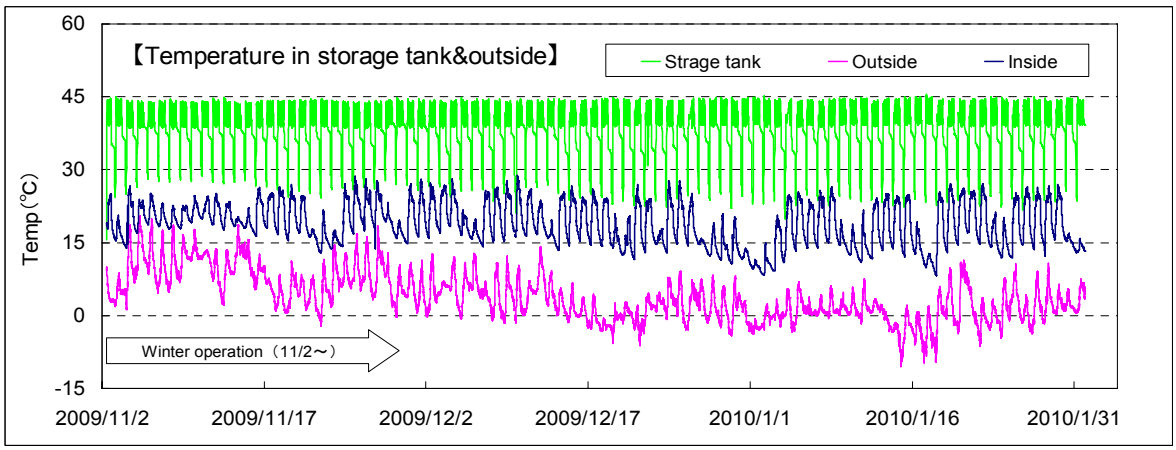


Figure 7 : Records of winter operation

The ambient temperature stayed within average during both operation periods.
The office temperature was set to 26℃ in summer and 23℃ in winter when we could experience way over 30℃ or below 0℃ outside.

3.3 Water level fluctuation

The natural water level stays approximately 125m above sea level around this area. The observation well #1 (near the north well) indicated no definite change of water level after the operation.
However, at the #2 well (near the new south well) , water level dropped, even though water was injected at the new south well in summer time. Yet no further change became evident during the winter operation, though water was pumped up from the same well this time.
From these facts, the changes were suspected to occur due to seasonal variations in natural water level and less likely to be caused by the operation itself.

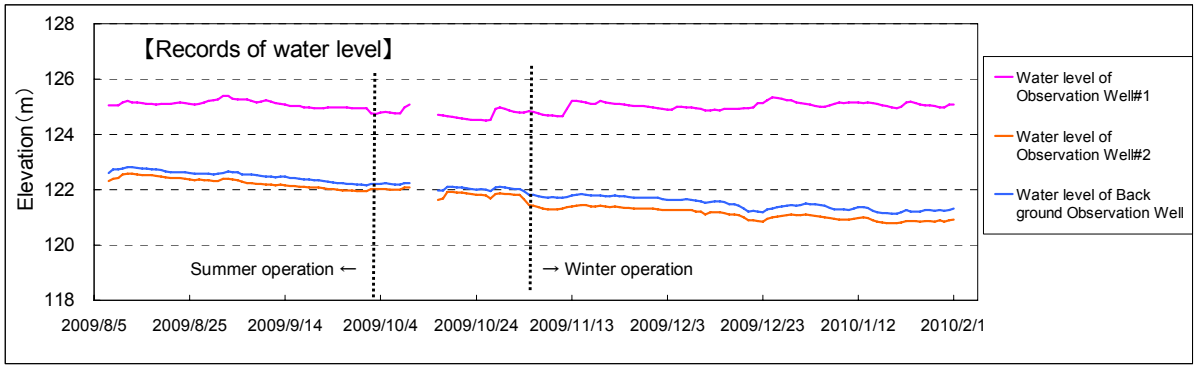


Figure 8 : Graph of the water level from the observation well (Daily average)

4 The evaluation of these facilities based from observation results

4.1 Reduction of the exhaust heat emissions into the atmosphere

Amount of the groundwater pumped up and injected into aquifer were stayed approximately same over the operation periods.
We have pumped up 4,131 ㎥ and injected exactly same amount during the summer operation.
From the daily study of pumping discharge and injection volume, and temperature change in piping, the heat budget (shown in Fig 10) and quantity of heat energy transfer to the ground from the new south well (shown in Fig 11) were derived.
Between August and September, the quantity of heat exchange (the exhaust heat) of heat pump for air-conditioning was 71GJ and the solar heat to collected at parking zone was 82GJ which would make 153GJ total, was injected into the aquifer,
Since summer time operation lasted only 2 month, we believed we could make twice as much of energy saving if we had operated 4 month, between June and September.
In another word, our facilities can reduced approximately 300GJ of artificial exhaust heat emitted into the atmosphere.

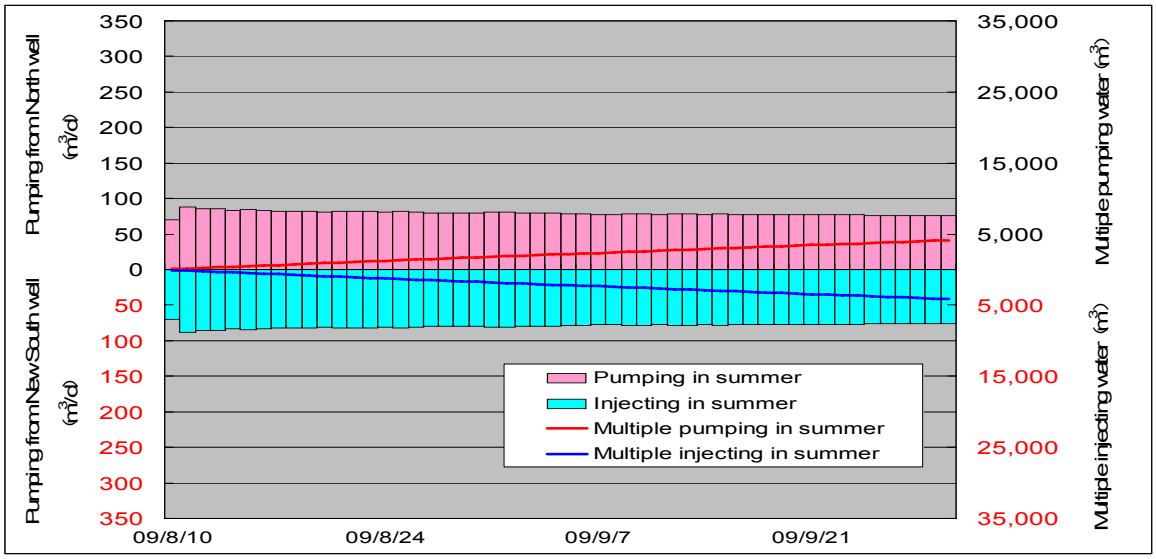


Figure 9 : Amount of pumping and injecting during summer operation

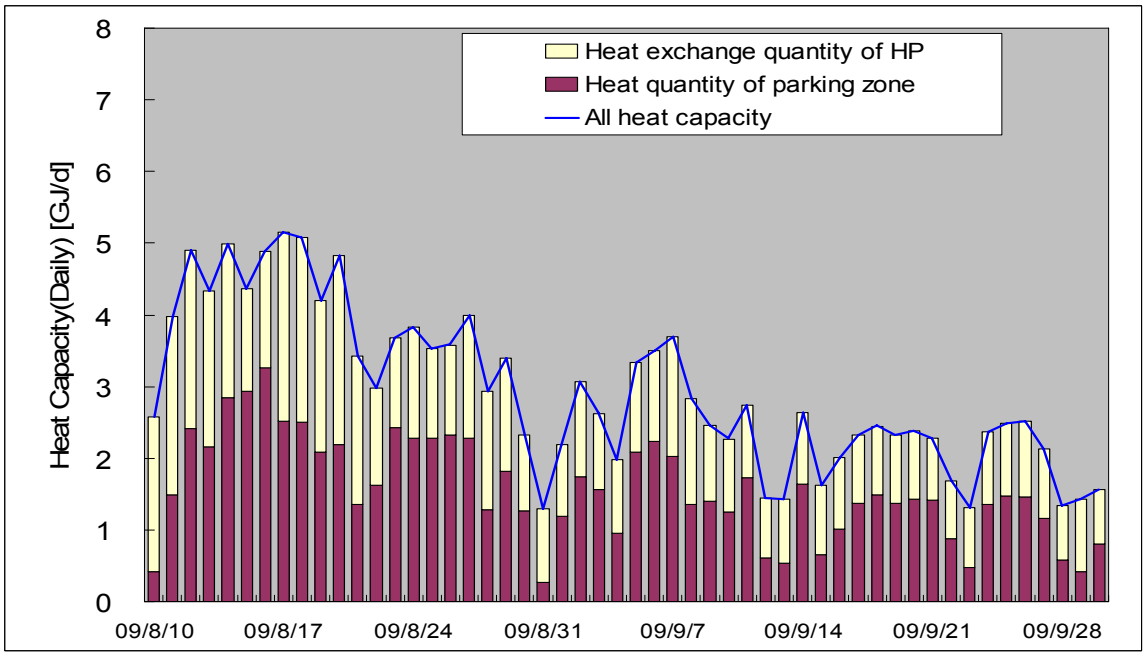


Figure 10 : Daily heat budget of summer operation (New south well)

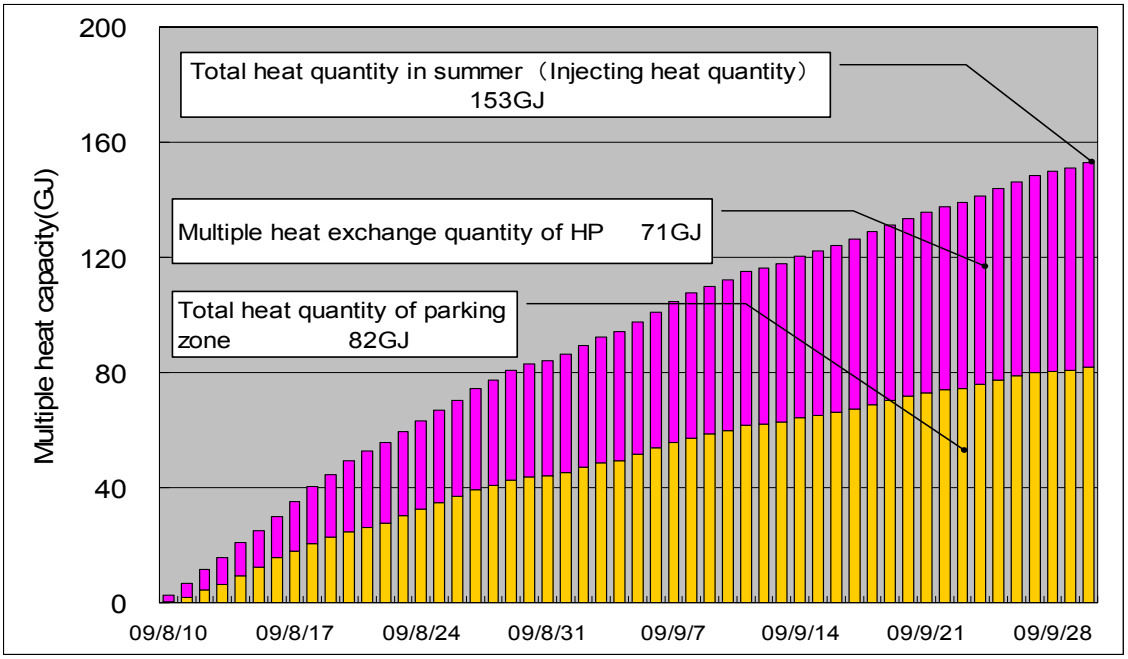


Figure 11 : Amount of heat injection into ground during summer operation (New south well)

4.2 The energy saving

COP of the facilities is listed in table 3 and daily results in Fig 12 and 13.
As will be noted from these, COP of heat pump for cooling is less than 3, and heating is less than 4. However, early reports from Katsuragi(1996) and Hiyama(1992), showed that it was 4.3 for winter heating. Considering the fact that facilities are 25 years old, the decline in number is most probably due to aging. By using the latest heat pump, COP for air conditioning will mark more than 5 will be expected.

Table 3 : Calculation result of this facility

	COP		
	HP only	Heat source	Air-conditioning
Summer cooling	2.87	2.34	2.11
Winter warming	3.26	2.64	2.26

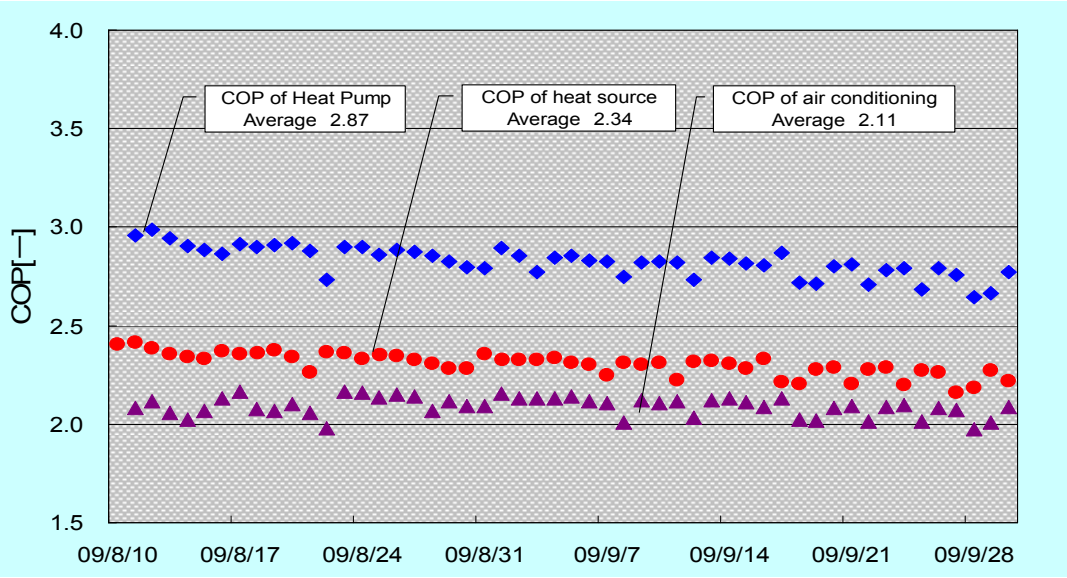


Figure 12 : COP in summer operation

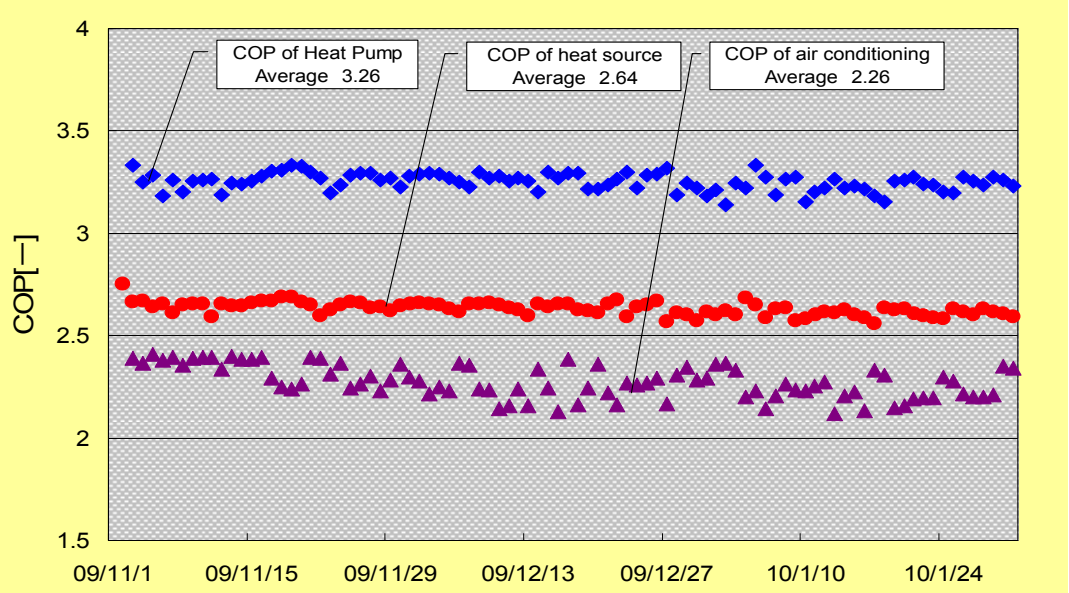


Figure 13 : COP in winter operation

4.3 The estimated underground temperature simulation

To evaluate environmental impact on underground temperature and groundwater temperature, FEFLOW Ver5.4 (numerical calculation software) was used.
Fig 14 and 15 show the results of the simulation calculated based on observation of maximum influenced area of warm and cold water zone and on the assumption of extended operation of the facilities for certain period of time.
Barely any change in temperature caused by injected summer heat energy was confirmed with long-term operation. This is because it is pumped up in winter consumed entirely during winter operation. Rather, quantity of the water needed in winter was greater than summer, so that unused cold energy stayed in the north well and expanded cold water zone along the underground water flow. A maximum influenced area with temperature change of 1℃ over 20 years were estimated about 65m.

Table 4 : Influence of temperature from injection well after operation finished (1℃)

Elapsed years	1 year	10 years	20 years
Warm Water Zone (New South Well)	12m	11m	11m
Cold Water Zone (North Well)	17m	47m	65m

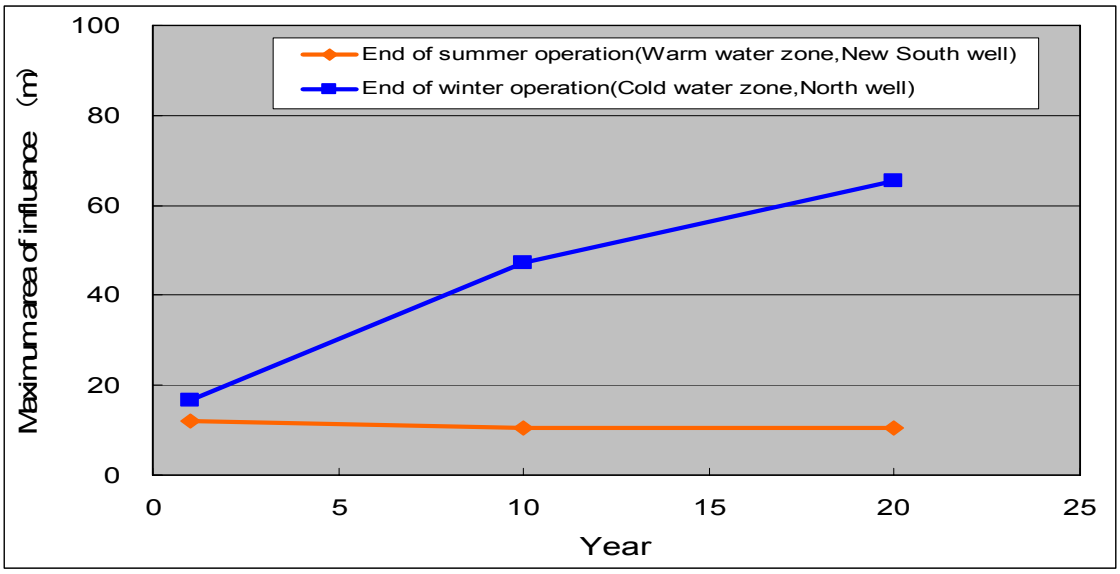


Figure 14 : Influence of temperature from injection well after operation finished

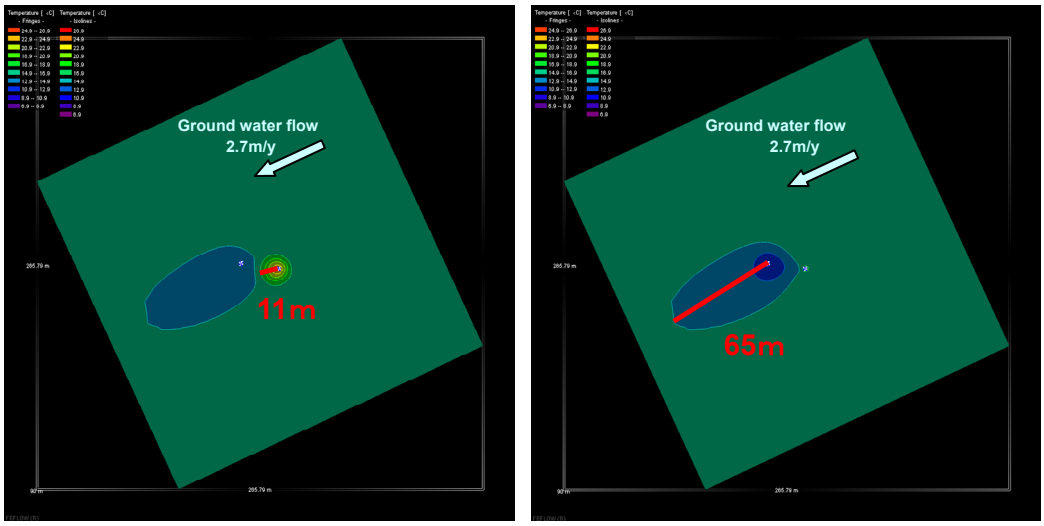


Figure 15 : 20 years simulation about area of influence (temperature) for warm water zone(left side) and cold water zone after 20 years

CONCLUSION:

The results from this case study are as follows;

1) Total of 153 GJ of heat energy was injected into the wells during summer operation. 71 GJ of which was come from the air-conditioning exhaust heat and 82 GJ was from solar energy collected in the parking zone. This clearly shows that the system reduces amount of heat emitted into the atmosphere and cools down the road temperature. Part of the heat energy stored in the aquifer is presumably utilized during winter operation.
2) Our facilities were built over a decade ago thus deteriorating of heat pumps and wells are evitable. However, COP still marks more than 2 point in both summer and winter.
3) Considering the fact that our facilities are situated in a cold region in Japan, and use of groundwater in winter time is greater than summer time, the heat energy is lost rather than remained in aquifer. Therefore, numerical simulation of heat transport shows the loss of 1℃, in 47m of the groundwater flow over a decade and 65m in two decades.

No other considerable environmental impact was reported.

This system has been adapted by the Japanese Ministry of Environment as one of the Cool City Project in 2009. We would like to express our deepest appreciation for their kind

offering of various data from the facilities.

REFERENCES

Takao YOKOYAMA・Hiromichi UMEMIYA・Hiroto ABIKO (1975) : Aquifer thermal storage with artificial recharge. Japanese Association of Groundwater Hydrology, 17-2, 55-67

Takao YOKOYAMA・Hiromichi UMEMIYA・Tatsuo TERAOKA・Hideo WATANABE・Kohei KATSURAGI・Keisuke KASAHARA(1980) : Seasonal thermal storage to use aquifer. Japan Society of Mechanical Engineer (Editing B), 46-402, 322-330.

Kohei KATSURAGI・Tadashi YOSHIDA・Takayuki HIYAMA(1986) : Aquifer thermal storage with the annual period, Groundwater, well, and pump, 28-3, 1-8

Takayuki HIYAMA(1992) : Snow Melting System using solar energy with aquifer and cold heat storage for air conditioning. Institute of snow management and control, 1992, 178-182