HEATING AND COOLING ENERGY SAVINGS USING THE TEMPERATURE DIFFERENCE BETWEEN PIPE WATER AND AIR

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ABSTRACT

K-water (Korea Water Resources Corporation, hereinafter “K-water”) is a public corporation, under the Ministry of Land, Infrastructure and Transporation, the Government agency in the Republic of Korea, that takes care of all water sector issues related to the development and management of multipurpose dam, hydro-power plants, water supply systems and other related facilities, both within Korea and overseas. In terms of the development of renewable energy, direct investments by K-water has been expanded, in recent years, to include solar, wind, and temperature difference technologies. Among them, temperature difference systems with a total capacity of 535RT (1882kW) at ten sites around the country are being operated by K-water, and a large system with a capacity of 3000RT (10.55MW) is under construction at the Lotte World Complex in Seoul, Korea. As well, K-water is planning to develop more temperature difference systems, totalling approximately 560MW, by 2021. The correlation between the temperature and type of the heat source (air or water) of a geothermal heat pump and the COP in winter was investigated. The economic feasibility of a cooling and heating system with an air heat source was the highest for units of 30RT and 50RT. Whereas units with a water heat source had good economic feasibility for capacities over 100RT. A study of heating and cooling energy savings for systems which utilize the temperature difference between water in a pipeline and air was carried out. In winter, the effect of ground heat exchange is approximately a 1.1°C temperature rise from 1.93°C to 3.04°C throughout 26km of the pipeline. Using an electric heater and heat storage tank can prevent equipment from freezing.

1. INTRODUCTION

Currently, the fossil fuel reserves such as petroleum and natural gas are expected to be depleted in approximately 40 and 60 years, respectively. The depletion of natural energy resources is a reality. The development of new energy technologies such as shale gas exploration technology has increased the duration of energy resources. However there are several problems with its use such as the limitations on its sustainability, pollution, environmental contamination and economic feasibility.

Recently, Germany and other European countries have made plans to phase out the usage of nuclear reactors because of potential disasters such as Japan's Fukushima nuclear radiation leak. As a result, the share of renewable energy is expected to increase.

Countries around the world are trying to follow the Kyoto Protocol and they are committed to reducing carbon dioxide. As the use of air-conditioning and heating machines in Korea continues to increase, so does the electrical energy demand during both summer and winter. Thus, the risks of large-scale black outs has increased significantly.

However, the building of new power plants and transmission facilities is a complex and challenging problem because of the distrust and anxiety of the population with regard to nuclear power plants and transmission facilities. Although renewable energy resouces, other than hydropower, supply lots of energy worldwide, South Korea has underestimated their importance. In recent years, geothermal or ground source heat pumps using water bodies as heat sources are increasingly receiving attention because dams and reservoirs have high heat capacities and are suitable for the production of thermal energy.

K-water seeks to expand the development of such systems, based on the exploitation of temperature differences, because it has access to dams, reservoirs, water supply pipes, etc., where conditions may be favourable.

In this paper, a case study is made of extraction of thermal energy from a pipeline suppying a water treatment plant.

2. K-WATER TEMPERATURE DIFFERENCE ENERGY RESEARCH AND DEVELOPMENT

2.1 Temperature difference energy status and Case Studies

K-water is a public company that manages water treatment plants, dams, hydroelectric power plants and related facilities. In recent years, the investments made by K-water in the field of renewable energy has been expanded to include solar, wind and temperature difference technology. K-water has been operating several temperature difference systems (a total of 10 sites, rated at 535RT or 1882kW) and a temperature difference system is under construction at Lotte World (capacity 3000RT). As well, K-water is planning to develop more temperature difference systems, totalling approximately 560MW, by 2021.

Table 1: Status of the K-water’s water management

Capacity (thousand m³/day)	Resource		Facilities		Pipeline (km)
	Dam	River	Dam	WTP	
17,682	13,452	4,231	13	40	4,910

The potential amount of heat energy that could be extracted from domestic rivers is estimated to be more than 190,000 Tcal per year.

Table 2: Status of temperature difference energy facilities operated by K-water.

Location	Capacity(RT)	Construction complete date
Total	**3,535**	
Juam Dam	10	'06. 11
Daechyung Dam	60	'07. 01
Chungju WTP	30	'07. 07
Buan Dam	65	'08. 10
Chungcheng operating center	30	'09. 11
Milyang WTP	80	'10. 12
Seougnam pilot plant	10	'10. 12
Asan WTP	65	'12. 01
Kumsan WTP	100	'12. 03
Chungju WTP	85	under construction
Lotte world	3,000	〃

South Korea introduced temperature difference energy systems as the country has favorable conditions such as warm water in winter and cold water in summer because of the seasonal and geographical characteristics. In addition, K-water operates water treatment plants (40 sites, capacity 17.6Million m^3/day), multipurpose dams (13 sites) and pipelines (4,910km).

Figure 1: Map of renewable of energy projects (including temperature difference systems) in South Korea

2.2. Case Studies

A study of the use of raw water in the Han River as a heat source was conducted by the K-water research institute with the aim of maximizing the use of the un-utilized energy. As well, K-water, together with the Farm Service Agency, studied in 2012 the use of riverbank filtration intake and recovery systems as heat sinks or sources for sustainable greenhouse air-conditioning and heating.

The disadvantages of the temperature difference energy systems during low temperature conditions in winter can be overcome by using a fuel cell as a heat source. The fuel cell uses shale gas to produce electricity and the by-product of thermal energy can be used to prevent the freezing of pipes in winter.

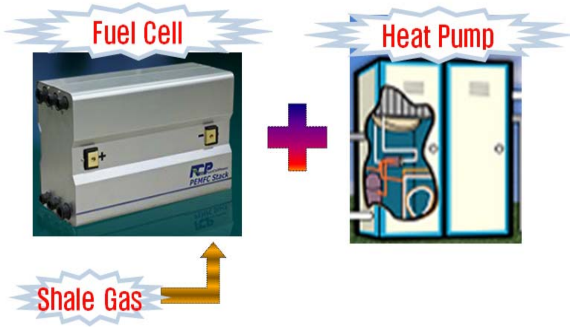


Figure 2: Hybrid temperature difference energy system using fuel cells

3. THEORY

Coefficient of performance(COP) of a heat pump unit is defined by equation (1) .

$$COP_{Unit} = \frac{cacity\,of\,the\,heat\,pump}{consumption\,of\,the\,heat\,pump} = \frac{Q}{W_{hp}} \quad (1)$$

Here W_{hp} is power comsumption of the heat pump and Q is the heat energy supplied. The cooling capacity(Q_c) is defined by equation (2) and the heating capacity(Q_h) is defined by equation (3).

$$\begin{aligned} Q_c &= c\dot{m}\Delta T - W_{hp} = c\rho\dot{q}\Delta T - W_{hp} \\ &= K\dot{q}\Delta T - W_{hp} \end{aligned} \quad (2)$$

$$\begin{aligned} Q_h &= c\dot{m}\Delta T + W_{hp} = c\rho\dot{q}\Delta T + W_{hp} \\ &= K\dot{q}\Delta T + W_{hp} \end{aligned} \quad (3)$$

Here c is the specific heat, $\dot{m}$ is mass flow, ρ is density, ΔT is temperature difference, K(=$c\rho$) is the volumetric specific heat. Therefore the coefficient of performance (COP) of a single heat pump unit can be expressed by equation (4) and (5):

$$\begin{aligned} COP_{unit,c} &= \frac{Q_c}{W_{hp}} = \frac{K\dot{q}\Delta T - W_{hp}}{W_{hp}} \\ &= \frac{K\dot{q}\Delta T}{W_{hp}} - 1 \end{aligned} \quad (4)$$

$$\begin{aligned} COP_{unit,h} &= \frac{Q_h}{W_{hp}} = \frac{K\dot{q}\Delta T + W_{hp}}{W_{hp}} \\ &= \frac{K\dot{q}\Delta T}{W_{hp}} + 1 \end{aligned} \quad (5)$$

$$W_{sys} = W_{hp} + W_{pump1} + W_{pump2} + W_{indoor\ units} \quad (6)$$

Here W_{hp} is the power consumption of the heat pump, W_{pump1} is the power consumption of the circulation pump, W_{pump2} is the power consumption of the intake pump, and $W_{indoor\ units}$ is the power consumption of the air conditioner.

Therefore, the coefficient of the performance of a temperature difference system is defined by equation (7) and (8).

$$COP_{sus,c} = \frac{Q_c}{W_{sus}} = \frac{K\dot{q}\Delta T - W_{hp}}{W_{sus}} \quad (7)$$

$$COP_{sus,h} = \frac{Q_h}{W_{sus}} = \frac{K\dot{q}\Delta T + W_{hp}}{W_{sus}} \quad (8)$$

4. EXPERIMENTAL EQUIPMENT AND DATA ACQUISITION

4.1 Pilot plant Equipment

The temperature difference energy system pilot plant for this study was installed in the Seongnam water treatment plant.

Figure 3: Seongnam water treatment plant

The pilot plant was designed so that the temperature difference energy system had a large capacity. It is composed of heat pumps with a 10RT capacity, 40,000 kcal / hr of the plate heat exchangers, and a 10 m^3 storage tank.

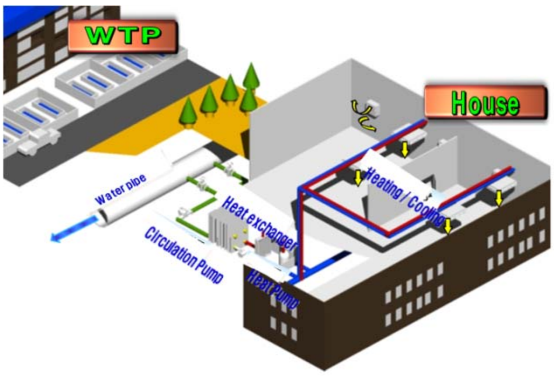


Figure 4: Diagram of a temperature difference energy system

- Installation location: Seongnam water treatment plant
- Capacity: approximately 10RT
- Type: water-water system
- Supply location: Office or the central operation room
- Refrigerant: R410a
- Temperature difference: Winter 3°C, other periods 5°C

The pilot plant was equipped with an electric heater, inverter and storage tank in order to take advantage of the frost protection system and to control the flow.

A variable heat pump system, dependent on the temperature, for the optimal operation of the raw water supply to allow control of the inverter was installed. The plant also includes flow meters, watt-hour meters, water level meters and a database for automatic operation.

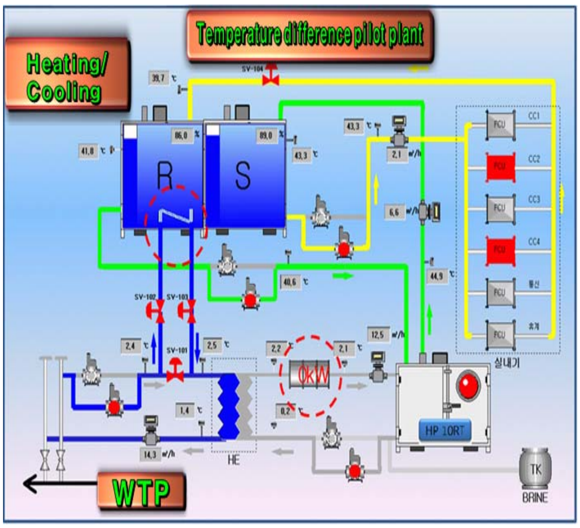


Figure 5: Temperature difference energy pilot plant

4.2 Temperature sensor for a thermal energy resource survey

To investigate the thermal energy resources, a thermocouple sensor was attached to the supply pipe to obtain temperature data. The datalogger is a 2-channel KTT300, the temperature sensor is a thermocouple and to give the same conditions independent of the depth of the installation point in the pipeline, a cable 20m in length was used.

		
a) KTT300 datalogger	b) Themocouple temperature sensor	c) Data collector

Figure 6: Datalogger, temperature sensor and data collector

Sensors and data loggers were installed on the wall to ensure they were waterproof, The sensors for each valve chambers were installed in pairs.

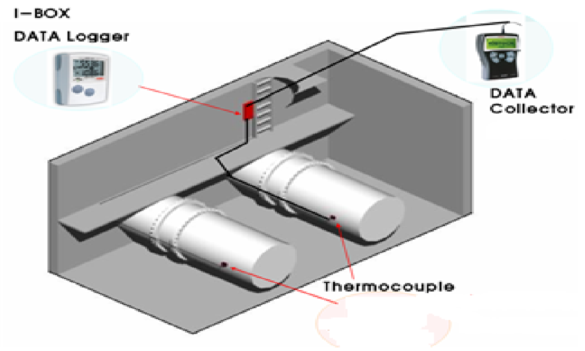


Figure 7: Installation configuration of the temperature sensor

5. RESULTS AND DISCUSSION

5.1 The relationship between temperature difference and the COP

5.1.1 Analysis of regional temperatures

The minimum temperature of the Chung-ju water treatment plant is 3 ~ 5°C in winter and the maximum temperature is 23 ~ 24°C in summer. The Chung-ju water treatment plant experiences a relatively small seasonal change in temperature because of the large intake capacity of the dam. The minimum temperature of the Ban-song water treatment plant is 1 ~ 3°C in winter and maximum temperature is 29 ~ 31°C in summer. The Ban-song water treatment plant uses reservoir water, but it experiences similar temperature variations to a river because of its shallow depth and small capacity. One of the important factors that determine the efficiency of a temperature difference energy system is the water resource temperature. Especially, the low temperature measurements are needed because the efficiency of the heat pump deteriorates when the temperature is below 5°C. The Chung-ju water treatment plant has a temperature above 5°C except for a few days in winter. However, the water temperature of the Ban-song water treatment plant is below 5°C for 70 days per year

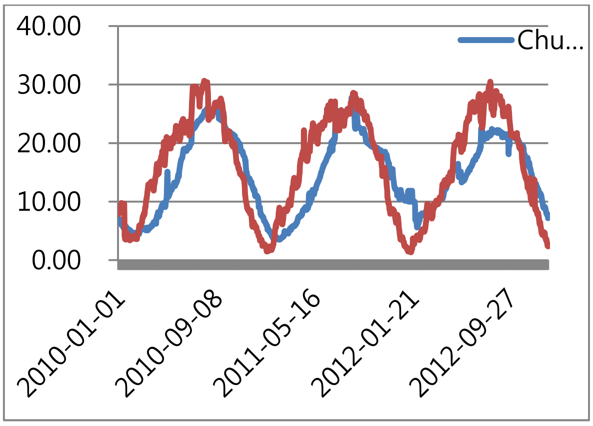


Figure 8: WTP temperature changes at Chung ju and Ban song

The differences of water temperature and air temperature in Chung ju and Ban-song water treatment plant were compared and it was found that the temperature difference for the Chung ju water treatment plant is 9.2°C in winter and 5.2°C in summer, whereas the temperature difference for the Ban song water treatment plant is 1 ~ 2°C in both seasons.

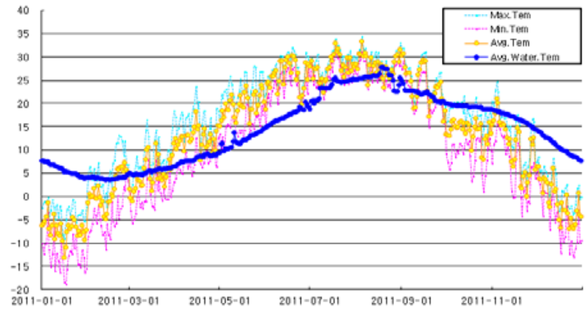


Figure 9: Comparison of the difference between the water temperature and air temperature in the Chung ju WTP

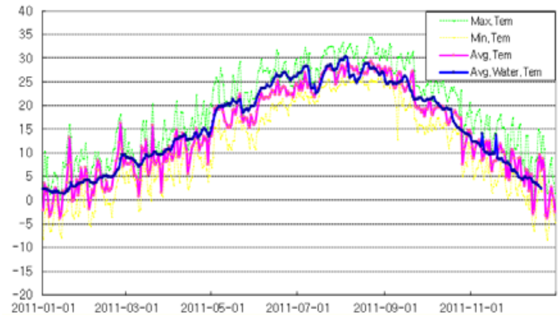


Figure 10: Comparison of the difference between the water temperature and air temperature in the Ban song WTP

5.1.2 Water temperature and heating performance

The relationship between the coefficient of performance (COP) and water temperature for a pilot plant were compared. COPsys is about 2.0 to 3.0 in winter and 3.5 to 4.5 in summer. The coefficient of performance decreases sharply when the water temperature falls below 5°C in winter. When the water temperature is lower than 1 ~ 2°C there is a risk of pipes freezing.

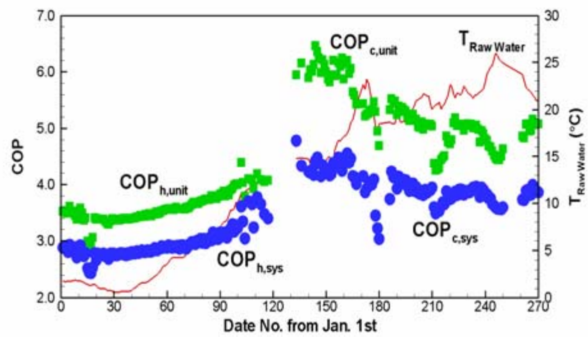


Figure 11: Water temperature and heating performance

5.2 Performance analysis of an installation with a thermal storage tank and electric heater

If the natural temperature of water is lower in the winter and the heat pump consumes heat energy from natural water, the heat exchanger and the pipe connected to the electric heater could be damaged.

To prevent this phenomenon, we prepared a freeze protection system that consists of a heat storage tank and electric heaters, and made an analysis of the effect.

If the temperature of natural inflow water is low, the water will get partially heated from the heat storage tank and the rising temperature prevents the equipment that is connected to the heat exchanger from freezing or bursting. If heat stored in the heat storage tank is not enough to raise the temperature sufficiently, the electric heater is activated.

In the Pilot Plant, 15kW of electric heating (5kW × 3) is installed as well as a 3.5kW heat pump. We conducted an efficiency analysis based on the freeze protection method using the heat storage tank and electric heaters. The results are shown in Table 3.

Table 3 Performance analysis of frost protection methods

		$T_{in,1}$ (℃)	$T_{in,2}$ (℃)	T_{out} (℃)	COP_{unit}	COP_{sys}	P_{hp} (kW)	P_{tot} (kW)
Heater Storage Tank	(23%)	1.15	1.65	0.15	3.36	2.77 (2.18)	10.1	12.2
Electricity Heater	5kW	1.17	←	0.00	3.36	2.01	10.1	16.8
	10kW	1.17	←	0.23	3.36	1.54	10.2	22.4
	15kW	1.17	←	0.50	3.36	1.27	10.4	27.3

If we install the heat storage tank, the cost will increase and the heat pump load will increase because some energy is consumed to protect the system from freezing.

On the other hand, if we use an electric heater, the COP of the system will be lower, electric fees will increase, but the installation will be inexpensive.

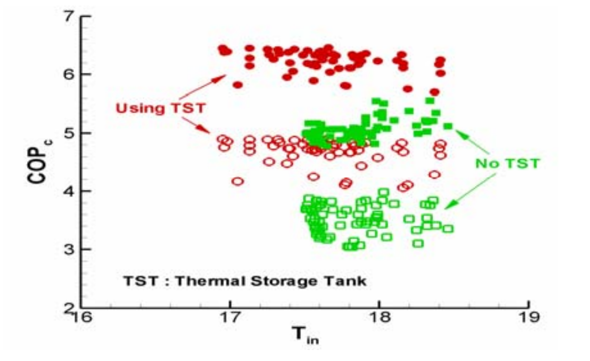


Figure 12: COP with a thermal storage tank

5.3 Underground heat exchanger effectiveness in winter

The effects of a winter underground heat exchanger are shown below. The change of temperature is measured by temperature sensors installed at regular intervals from the point of water intake.

When comparing the temperature rise when passing through underground piping that has length of 26km, there was a 1.1°C temperature rise from 1.93°C to 3.04°C in February.

In addition, temperature difference energy would be 5,766.3Tcal/year when using a heat pump placed in the Han River. It is calculated that the Temperature difference energy is potentially more than 12 times the amount of energy that can be produced by the Shihwa Tidal Power Plant.

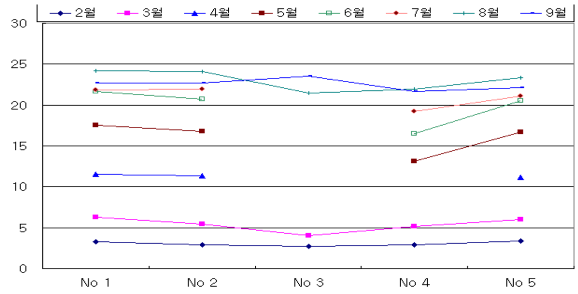


Figure 13: Temperature of the heat exchanger - region A

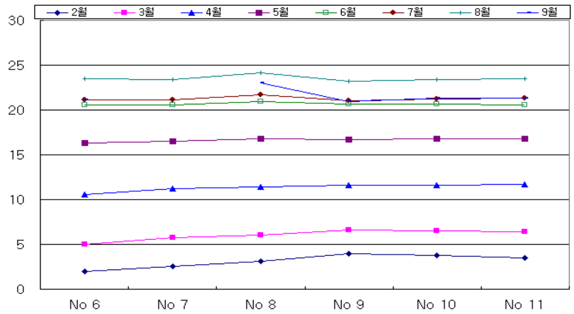


Figure 14: Temperature of the heat exchanger - region B

5.4 Comparison of heat pump configurations

5.4 .1 Water to water heat pump systems

A cooling and heating system using water to water heat exchange is shown in Figure 15. This type of plant transfers temperature difference energy to an indoor heat exchanger in two stages. First by transferring heat from the raw water to a heat exchanger using a raw water pump. The first heat exchanger is part of the heat pump circuit which tranfers energy to an indoor heating or cooling device via a second heat exchanger.

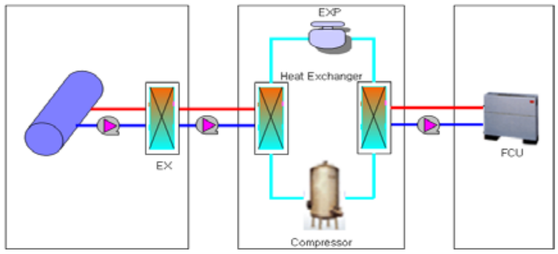


Figure 15: Water to water heat pump system

5.4.2 Water to air heat pump system

A cooling and heating system based on water to refrigerant heat exchange is same as one using water to water heat exchange except for the circulating pump which is used for supplying heat indoors. In other words, it is the type that transfers temperature difference energy from raw water to refrigerant by heat exchanging in FCU indoor that has a pipeline connected to the heat pump inside.

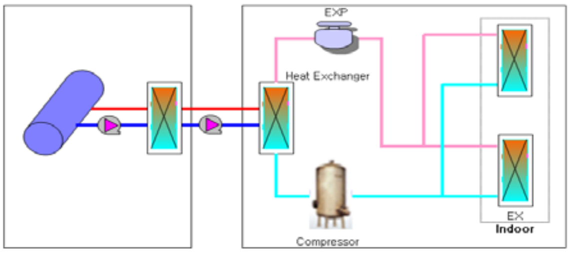
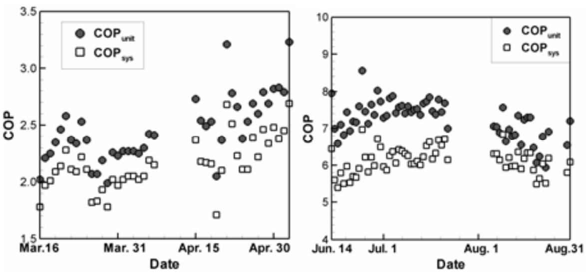


Figure 16: Water to air heat pump system

The correlation between water temperature of the heat source for a geothermal heat pump and the COP in winter was compared.

Economic evaluations including initial investment cost, electricity cost, etc. were compared for plant with capacities of 30, 50, 100, 200, 400, 1000RT using air heat sources and water heat sources, respectively. The economic feasibility of the cooling and heating system with an air heat source was the highest for plant with a capacity in the range 30RT and 50RT. Whereas water to air type with a water heat source had good economic feasibility for plant with capacities over 100RT.



a) heating b) cooling

Figure 17: Water to air heat pumps - variations in COP

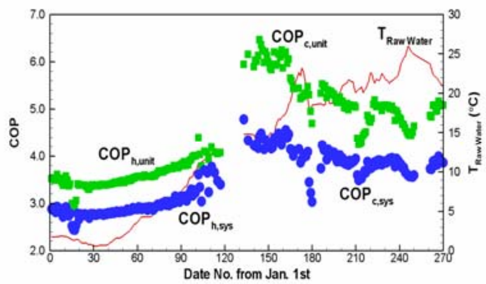


Figure 18: Water to water heat pumps - variations in COP

6. CONCLUSION

In order to take advantage of the unused energy in a waterworks pipe, we investigated water treatment plant inlet raw water and the thermal energy in the pipe.

The requirements for optimal performance of such a system are as follows:

1) Finding favorable sites to use the deep water of dams because the temperature difference between water and air is proportional to COP, as shown by the data from the Chung-ju and Ban-song water treatment plants.

2) Using an electric heater and heat storage tank can prevent equipment from freezing, for the heat storage tank, there is a disavantage in that the operation and installation costs increase. For the electric heater, the installation cost is cheap but the COP decreases.

3) In winter, the effect of underground heat exchange is approximately a 1.1°C rise, from 1.93°C to 3.04°C, along a 26km pipeline.

4) For plant with a capacity between 30RT and 50RT, the economics of the air source heating and cooling system was the best, while for plant with capacities of more than 100RT, the economics of the water-air source heating and cooling system were most favourable.

REFERENCES

Cho, Y. and Yun, R., 2011, ″A Raw Water Source Heat Pump Air-conditioning System,″ Energy and Buildings, Vol. 43, pp. 3068~3073.

Choi, H.-M., Lee, J.-Y., Cheon, J.-Y., Jun, S.-C, Kwon, H.-P., 2010, ″Estimation of Optimal Pumping Rate, Well Efficiency and Radius of Influence Using Step-Drawdown Tests,″ Journal of Engineering Geology, Vol. 20, No. 2, pp. 127~136.

Cho, Y. and Lee, D. K ., 2012, Practical Use of Raw Water-Source Heat Pump System

Oh, S. H., Yun, R., and Cho, Y., 2011, Analysis of the cooling heating operation characteristics for the raw water source heat pump and the air source heat pump in water treatment facility, Proc. of Korean Society of Mechanical Engineers Annual Fall Conference.

Cho, Y. Kim. D. K, 2012, Development of Riverbank Filtration Water Supply and Return System for Sustainable Green House Heating and Cooling of Korean Society of Mechanical Engineers Annual Fall Conference.

Cho, Y. Kim. D. K, 2012, The study on heat source of raw water in Hangang area water supply system, K-water, Korea.