

Application of geothermal heat pumps in renovated campus building of Korea

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ABSTRACT: Recently, geothermal heat pumps (GHPs), which are normally known as ground source heat pumps (GSHPs), offer some advantages for heating and cooling of residential and commercial buildings due to the higher energy efficiency compared with conventional EHP system. In Korea, the renewable energy sources are forced to apply to the public buildings, which have over 3,000 m² of floor area according to the law. While GHPs may be more costly to install initially than regular heat pumps, they can also produce markedly lower energy bills. For this reason, GHPs are scrutinized as the heating and cooling alternatives in renovation of the campus buildings in Korea. In this study, we would like to investigate the application methods of GHPs for renovation of campus building, and to compare the energy costs of GHPs with that of conventional system. Also, the objective of this study is to present an operation status of GSHPs in renovated campus building as an example.

Keywords: Geothermal heat pumps (GHPs), Campus building renovation, Energy bills,

NOMENCLATURE

C	specific heat, [kJ/kg K]
COP	heating coefficient of performance, [dimensionless]
T	temperature, [K]
EER	cooling energy efficiency ratio, [Kcal/hr W]

Abbreviations

ASHPs	Air source heat pumps
GHPs	Geothermal heat pumps
GSHPs	Ground source heat pumps
NRE	New & Renewable Energy
NREC	New & Renewable Energy Center
PAC	Packaged-type air conditioner
EHP	Electric heat pump

1. INTRODUCTION

Geothermal heat pumps (GHPs), which are normally known as ground source heat pumps (GSHPs) can achieve a higher coefficient of performance (COP) than conventional air source heat pumps (ASHPs), because the ground temperature is higher in winter and lower in summer than the air. For this reason, although somewhat higher in first cost, this system can quickly repay this cost premium through savings in energy costs in the right application. Also, in Korea, the government established the New & Renewable Energy Center (NREC) under the Korea Energy Management

Corporation (KEMCO) and empowered the NREC to take charge of development and deployment of a lot of energy technologies such as geothermal energy, solar energy, etc. To promote the installation of geothermal energy equipment, there are various promotion programs such as subsidy program, obligative applications of NRE in public facilities, and full supports for regional energy program. In Korea, the renewable energy sources are forced to apply to the public buildings, which have over 3,000 m² of floor area according to the law. With this background, GHPs has been scrutinized as the heating and cooling alternatives in renovation of the campus buildings. In this study, we would like to investigate the application methods of GHPs for renovation of campus building, and to compare the energy costs of GHPs with that of conventional system. Also, the objective of this study is to present an operation status of GSHPs in renovated campus building as an example.

2. Energy consumption and energy rates for campus buildings in Korea

2.1 Energy consumption in campus buildings

For the past decades, the energy consumption of university in Korea has been gradually rising because of the severe outdoor temperatures with regard to recent global warming and also sudden expansion of campus buildings. Because the function of campus buildings has been complicated according to the social needs of not only education but also research & development, it is inevitable to increase gradually in the energy consumption of university. According to the recent article regarding the energy consumption of universities in Korea, the total energy consumption gets to 397,130 TOE, which is the sum of 75 universities' among the whole country (see Fig. 1). It is the same value of 353,000 tons in CO₂ emission. That was a remarkable value because 1.3 millions of Korean pine

trees should be planted to absorb the emitted CO₂ gas. Furthermore, it was very amazing that 23 universities were included in 190 energy-guzzling buildings in the whole country. Also it was a notable issue that the portion of electrical energy consumption was very large. Similarly, so many universities in the world have perceived the energy problems for each campus and tried to reduce the energy consumption.

Most of the newly-built or renovated buildings in university have tried to use the most efficient energy sources, construction materials for walls and windows, electronic appliances, and electric lightings. For example, the NRE such as geothermal energy and solar PV system has been considered as an alternative of conventional energy sources. Also examples include the emphasis on the thermal insulation of interior and exterior walls, and high efficient mechanical and electrical equipments. Most buildings have the HVAC systems operated by computer over the campus network.

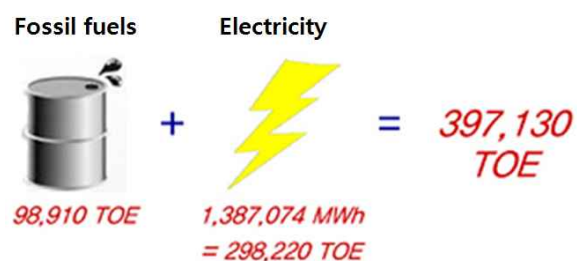


Figure 1: Statistical record of energy consumption of university in Korea (referred to the news article about the energy consumption of campus in Korea, *Ohmynews*, <http://www.ohmynews.com>)

2.2 Energy rates for campus buildings in Korea

In Korea, there are several kinds of main energy sources such as oil, gas, electricity, and thermal energy. In spite of the surging domestic energy consumption, Korean government has been able to maintain a stable supply of energy through the continuous expansion of energy supply facilities. As for energy demand by source, because overall oil consumption is expected

to increase by annual average of 2% or more by 2010 and the oil price is gradually increasing every year, the demand of oil for heating equipment are decreasing in campus buildings, although the current heating sources were oil-fired boilers. As compared to the oil supply, gas supply is a little more stable since it is deposited widely around the world. For this reason, the consumption of gas is expected to increase rapidly in residential and campus buildings. Electricity demands also continue to grow as people demand high-quality energy. As shown in Fig. 1, the electricity consumption in campus building was enormous. Because there are so many equipments for research and education in campus buildings, the demand for electricity will be more increasing compared to any other energy sources. NRE (New and renewable energy) is also expected to apply to the HVAC system of campus buildings because of changing attitude regarding fuel economy and the subsidy program of government. Especially the geothermal energy using GHPs is normally recognized as an alternative for the current PAC (Packaged-type air conditioner) system.

In campus buildings, the electricity rates have been different from the other facilities like residential and industrial buildings. (Refer to Table I) Because of the low prices compared to the residential electricity, the individual PAC system was normally used for cooling. As the installation of PAC system has been generalized in lecture rooms, the electricity consumption also rapidly increased. For this reason, air-source EHPs (electric heat pump) were firstly considered as the heating and cooling equipment. Though the easy installation and a little initial cost for applying the air-source EHPs to campus buildings, the operation cost was great compared to the NRE. As the energy rates (oil, gas or electricity) have increased consistently and the university has an accumulated deficit for energy costs, the common concern has been focused to the NRE such as geothermal energy.

Table I: Comparison of energy rates in Korea (2007-2008).

For educational electricity (High-voltage A)

	Basic rate (Won/kW)	summer	winter (Won/kWh)	others
Alt. 1	4,340	72.6	52.9	46.7
Alt. 2	4,970	69.3	49.3	43.5

For night-time electricity (B type)

Year	Basic rate (Won/kW)	winter	other seasons (Won/kWh)	daytime
2007	5,890	42.9	33.1	72.8
2008	4,970	52.1	37.9	70.6

For residential electricity (Low-voltage)

	Basic rate (Won/kW)	energy rates (Won/kWh)
0 – 100kWh	370	55.10
101-200kWh	820	113.80
201-300kWh	1,430	168.30
301-400kWh	3,420	248.60
401-500kWh	6,410	366.40
above 501kWh	11,750	643.90

For oil for boiler (Won/liter)

Year	
2007	1,050
2008	rapidly increasing recently

2.3 Subsidy program for renewable energy application in Korea

Korea is ranked 10th in energy consumption and carbon dioxide emissions and 7th in oil consumption in the world. So to reduce the energy consumption and to promote the usage of the NRE, Korean government will likely offer incentives for nurturing alternative sources of energy. NREC in Korea is making every effort to lower the initial cost for NRE and the price has indeed been falling down. Also the center is encouraging public application of NRE through incentives including loans, subsidies and feed-in tariffs as well as

launching surveys, training field experts and overseas promotion.

Subsidy programs consist of model deployment program, which is to promote the marketing of newly developed NRE systems and general deployment program which is to increase the utilization of NRE in private sector. In 2008, government subsidizes 80% of the installation costs as a model deployment program, and 50% of the associated installation costs as a general deployment program.

New or renovated public buildings which have over 3,000m² of total floor area were obliged by law to apply more than 5% of their total construction expenses to install NRE facilities.

3. Application of geothermal heat pumps in renovated campus building

Recently, as the geothermal energy has been considered to the alternative for saving electrical energy consumption, there have been so many researches about GHPs and field applications in residential and educational facilities in Korea. In this study, we would like to investigate the application methods of GHPs as an example and to compare the energy costs of GHPs with that of conventional system. For this purpose, the renovated campus building (see Fig. 2), which is located in Cheong-Ju city of Korea, has been investigated and energy bills were analyzed.

3.1 Campus building renovation

The summary of renovated campus building is the following Table II. The total floor area is 14,167m² and the conditioned space 8,480m². There are several types of room, such as lecture room, professor's office, department's office, seminar room, computer room, etc. For space heating and cooling with domestic hot water supply, 50 RT three GHPs with water storage tank were installed in the basement floor of building. Among the several type of ground heat source/sink, the open loop heat pumps,

i.e. standing column well method, were applied to the building mechanical system.



Figure 2: Photo of renovated building

Table II: Summary of renovated building

Category	Description
Building type	Educational facility
Floor space	14,167 m ²
Service	Space heating/cooling Domestic hot water supply
Application methods	Standing Column Well with water storage tank
Water storage tank	13.5m x 8m x 5m 540 ton
Domestic hot water	3 ton
Control	Automatic control system
Terminal unit	FCUs
Conditioned space	8,480 m ²
Heat pump	50 RT, 3 EA
No. of borehole	6 holes
Depth of borehole	400 m

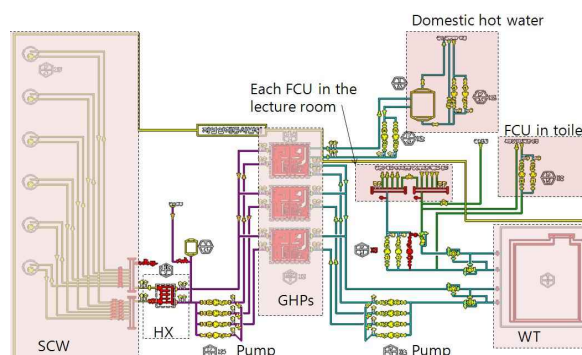


Figure 3: GHPs system configuration

GHPs that use groundwater drawn from wells as a heat source/sink are commonly known as standing column well (SCW) systems. As shown in Fig. 3, the GHPs system in this project was composed of boreholes (SCW), water storage tank and heat exchanger, etc. In this SCW system, the heat exchange rate could be enhanced by the pumping action, which promotes movement of groundwater and induces advective heat transfer. Compared to the GHPs system with closed loop heat exchangers (U-tube), the efficiency of SCW system may be improved because the fluid flows through the GHPs are closer to the mean ground temperature. The ground heat exchanger in such system consists of a vertical borehole that is filled with groundwater up to the level of the water table (i.e., similar construction to a domestic water well). Water is circulated from the well through the heat pump in an open loop pipe circuit to the HX (heat exchanger). The piping from water storage tank was connected to the each FCUs (fan coil units) and domestic hot water supply.

Building mechanical system have been renovated and upgraded to improve energy savings. The university is pursuing thermal storage as an alternative to add the capacity and shift energy use to night to reduce electrical costs. As shown in Fig. 4, the night-time electricity (from 22:00 p.m. to 8:00 a.m.), which is nearly half the price of day-time electricity, is used for making the water of storage tank cool or heat.

Through the implementation of a central control system for mechanical equipment using the campus network, it is possible to allow the several level of control over the HVAC system in each room of buildings depending on the schedule of occupants. Most room temperatures can be monitored remotely and fans can be started or stopped. Various information regarding the operation of GHPs are available at Department of Facilities in university. Technicians can also access the system from their desktop computer to look at problems during operation. Where conditions allow, all

buildings have a scheduled according to the pre-determined timetables. Since almost no waste heat is discharged to the atmosphere, the use of these systems is expected to contribute to a reduction of the heat island effect. Also it could lower the demand for electrical peak power during the daytime operation.

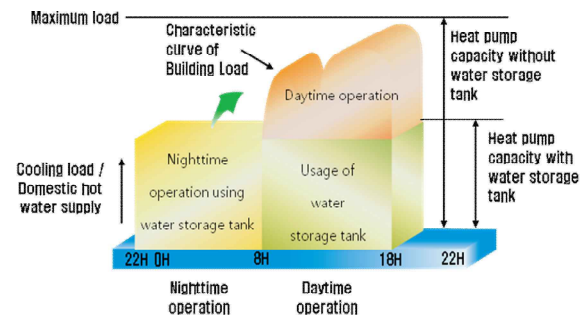


Figure 4: Operation strategy of GHPs with water storage tank

3.2 Application of geothermal heat pump system

The first step for the installation of a GHP system is to find the characteristics of the site in terms of a geology and ground water availability. Normally, the ground-source industry for domestic water supply has not fully taken a consideration of the geological information in the past. But in designing the HVAC system, it is necessary to know the water temperature distribution of heat exchange borehole and the COP according to the leaving or entering water temperature. The temperature in the well is shown in Fig. 5.

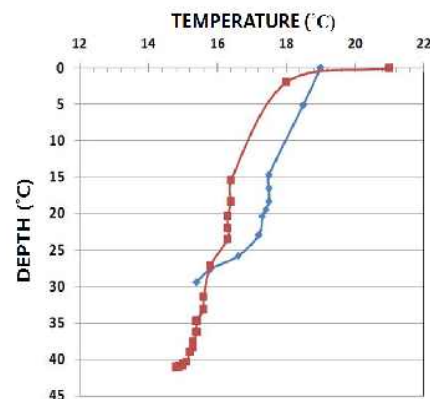


Figure 5: Measurement results of well temperature

Table III: COP test results of GHP

LFT (°C)	EFT (°C)	Capacity (Mcal/hr)	Power (kW)	COP (heating)
40	6	133.5	35.95	4.32
	8	141.8	36.27	4.54
	10	150.5	36.61	4.78
	12	159.7	36.98	5.02
	14	169.3	37.36	5.27
45	6	131.2	39.41	3.87
	8	139.1	39.72	4.07
	10	147.4	40.05	4.28
	12	156.2	40.41	4.50
	14	165.5	40.78	4.72
50	6	129.2	43.25	3.47
	8	136.7	43.56	3.65
	10	144.6	43.89	3.83
	12	153.0	44.24	4.02
	14	161.9	44.60	4.22
55	6	127.6	47.51	3.12
	8	134.6	47.82	3.27
	10	142.1	48.16	3.43
	12	150.0	48.51	3.60
	14	158.4	48.87	3.77
LFT (°C)	EFT (°C)	Capacity (Mcal/hr)	Power (kW)	COP (cooling)
4	20	119.3	27.93	4.97
	25	114.6	31.07	4.29
	30	109.8	33.82	3.77
	35	104.5	36.88	3.30
	40	99.2	40.32	2.86
5	20	123.8	28.16	5.11
	25	119.0	31.27	4.42
	30	113.9	34.01	3.90
	35	108.5	36.88	3.42
	40	103.0	40.50	2.96
6	20	128.4	28.39	5.26
	25	123.4	31.48	4.56
	30	118.2	34.21	4.02
	35	112.6	37.26	3.52
	40	106.9	40.68	3.06
7	20	133.0	28.64	5.40
	25	127.9	31.70	4.69
	30	122.6	34.41	4.14
	35	116.9	37.46	3.63
	40	110.9	40.87	3.16

LLT : Leaving fluid temperature

EFT : Entering fluid temperature

The minimum temperature in the well was 14.8°C at a depth of about 40m and it would be fluctuated between the ranges of $\pm 1^\circ\text{C}$ according to the circulation quantity of water flow. As shown in Table III, the COP for heating has reached from 3.12 to 5.27 according to the LFT (leaving fluid temperature) and EFT (Entering fluid temperature). Also the COP for cooling has reached from 2.86 to 5.49.

4. Analysis of the energy consumption and operating costs

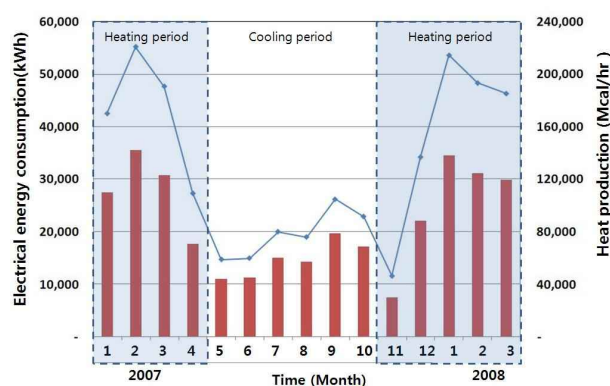
After the building renovation in 2006, the GHP system has been operated during heating and cooling seasons. According to the usual academic schedule, GHP system integrated with water storage tank was operated. For example, the lecture rooms or seminar rooms were scheduled in central control system during the 1st and 2nd semesters, and the professor's offices or department's offices were operated by using the individual room controller.

During the measurement period in winter, the outdoor temperature was about average 0°C and the room temperature was kept at 18-20°C. This temperature was sufficient in the heating condition of Korea. From these measurements, it was verified that heating by GHP can be used instead of the conventional oil-boiler in winter in Cheong-Ju, Korea. Moreover, it is possible to decrease the discharge of carbon dioxide with the GHP system.

We have firstly analyzed the monitoring data of electrical energy consumption, which are composed of daytime electricity consumption, night time electricity consumption, and electricity consumption of water circulation pumps every month. Based on the each electrical energy consumption, the amount of heat production from the GHP was calculated according to the assumptions like Table IV.

Table IV: Assumptions for calculation of the amount of heat production

GHP with water storage system (150RT)			
Electrical Consumption (kW)	Number of equipment	COP Heating	COP Cooling
62.0	2.5	3.0	3.5
Operating time of circulation pump(hr/day)		Efficiency of water storage (%)	
15		95%	

**Figure 6:** Monitoring data of electrical energy consumption and heat production

As shown in Fig. 6, the electrical energy consumption in 2007 was maximum 55,210 kWh and in 2008 was maximum 53,601 kWh. Compared to the winter season, the energy consumption in summer was a smaller quantity. It is because the operation time of GHP system in winter is longer than that in summer.

To compare the operating costs of GHP system with those of conventional system, as shown in Table V, the capacity of boiler with 2 ton and the 12 PAC with 30HP capacity were assumed. The oil price was assumed like Table I.

In comparison results, the sum of operating costs of GHP system was about 34 million (won) in 2007, however those of oil-fired boiler with PAC system was about 92 million (won). That was nearly 3 times per year.

Table V: Assumptions for Comparison of operating costs

Oil-fired boiler(2 ton) with PAC(30RT x 12)		
Heating value (kcal/liter)	Boiler efficiency (%)	Operating time (hr/day)
62.0	92	7.5
Heat extraction rate(kcal/kW)	Electric power (kW)	COP
860	338	2.7

Table VI: Comparison of total sum of operating costs (in 2007)

GHP with water storage system	Oil-fired boiler with PAC system
34,155,086 won	92,536,437 won

And the initial cost for GSHP systems depends on where you live and which this system you use. If the use of GHP systems becomes more popular, it will reduce the cost of drilling boreholes for the vertical ground heat exchangers, which is the main cause of the high initial cost. If a 50% subsidy is obtained from the government to promote the introduction of these systems, the initial investment for installation of the geothermal heat pump can be recovered within a few years.

5. CONCLUSION

In this study, we would like to investigate the application of GHPs for renovation of campus building, and to compare the energy costs of GHPs with that of conventional system. When the GHP system has been operated during the whole year, it was verified that heating and cooling by GHP could effectively replace the current oil-fired boiler with PAC system. Also the operating costs could be nearly decreased by one third of the current heating and cooling systems.

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