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Utilising Unused Energy Resources for Sustainable Heating and Cooling System in Buildings: A Case Study of Geothermal Energy and Water Sources in a University

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Abstract: Recently, Korea has become increasingly interested in unused, but possibly useful energy resources, due to the world-wide controversy over nuclear power and limitations in renewable energy production. Among these unused resources, the water that is produced in our surroundings is available as a potential energy source for heating, cooling and domestic hot water. This water is relatively stable on the supply side, available as a high-efficiency source in all seasons, and is continuously replenished without polluting the environment. This paper analyses the energy savings generated based on the actual use of a sustainable heating and cooling system that operates using the water escaping from a nearby building. The results indicate the value of protecting the environment as well as reducing energy consumption and associated costs.

Keywords: unused energy resource; sustainable system; underground water; building energy efficiency; university building

1. Introduction

A large number of countries have started to optimise their energy use and/or promote the development and supply of non-fossil energy resources, as enshrined in the Paris Climate Agreement, the new international agreement replacing the Kyoto Protocol to reduce greenhouse gas emissions. However, the safety of nuclear power, on which numerous countries rely heavily to produce their electricity, has been the subject of considerable controversy in terms of the consequences of the impact of the natural disasters and human-made hazards associated with this energy source [1]. For this reason, increased reliance on renewable energy as an alternative to conventional fuel is an inevitable trend [2].

Korea has a small land area and its topography (approximately 70% of the nation's territory is mountainous land) is limited in renewable energy sources. Recently, there has been increasing interest in unused but possibly useful energy resources that are produced in our surroundings. Among these resources, the potential energy of water (rivers, streams, wastewater, etc.) is available for heating, cooling and domestic hot water; it is relatively stable on the supply side as there is a substantial reserve of water, in contrast to conventional energy sources such as petroleum, coal and natural gas; its temperature does not respond to seasonal temperature changes and hence it is available as cooling water and a high-efficiency source for heat pump systems; and its energy is continuously replenished without polluting the environment [3,4].

2. Related Studies

Underground water escaping through pipelines in Seoul City's subway can be used as a source for heat pump systems and a heat exchanger for heating and cooling buildings, because the water is maintained at a constant temperature (12–23 degrees Celsius) and lies above the living water level [5]. However, according to the Seoul Metropolitan Government Report [6], 78.1% and 19.9% of waste water in 23 subway stations (a daily waste water volume of 68,446 m^3 on 31 December 2014) are discharged into streams and sewage treatment plants, respectively. Only a small proportion (roughly 2%) of water is being reused for the operation of building systems, toilets, road surface cleaning, landscape irrigation and so forth. Of all Seoul subway stations, only 13% (three stations) are using technology for energy recovery and waste reuse, of which 67% (two stations) use water as a source to heat and cool their buildings, despite the low interest rate on loans under a building retrofit project by the Seoul Metropolitan Government.

Numerous articles on space heating and cooling systems combining heat pumps (typically air-to-air, geothermal and water sources) and heat exchangers have been published over the past few years. Of these, few have discussed water source heat pumps and the availability of water as an alternative energy source, the development of these systems, and improving their operation and performance. Some of these studies have concentrated on the availability of unused or wasted water as an alternative energy source. For example, Park et al. [7] calculated the theoretical amount of temperature difference energy available (the potential energy reserve) by utilizing distance measures to restore water quality in rivers and latent heat fluxes in a heat pump when considering climate change effects. Lee et al. [4] investigated the sewage water temperature that has the greatest impact on system performance under seasonal weather variations and suggested a system configuration using an existing absorption refrigeration and heat pump through computer simulation results. Milenic et al. [8] investigated the feasibility of using groundwater as a hydro-geothermal energy source for heat pump systems, with a focus on the quality and quantity of this energy source; while Nam and Ooka [9] showed the importance of groundwater (from a well or surface) flow location and conditions for optimum heat pump systems by comparing the heat–water transfer simulation and experimental results.

Considerable effort has been applied in studies analyzing system performance and improvement. Cho and Yun [10] conducted simulation experiments analysing the performance of a raw water source heat pump system in a water treatment facility compared with an air source heat pump system with respect to air temperature changes from January to December; Park et al. [11] also performed a comparative simulation study on the performance of heat pump systems according to the heat source (such as an existing system using an air source heat pump with a liquid natural gas (LNG) boiler, a river water source heat pump, and a ground source heat pump). On the other hand, Chan Chen et al. [12] assessed an underground water source heat pump system for apartment buildings in terms of its operating and control conditions, and noted an increase in electricity consumption and operation costs due to technological problems (not changing the fluid flow according to the operating load). The electricity required for the heat pump was estimated from monthly energy use changes; Bae et al. [13] suggested optimising system operations by controlling the fluid flow through an electronic expansion valve in the heat exchanger for simultaneous cooling and heating by experimentation. Luo et al. [14] analyzed heating and cooling performances of a ground source heat pump system installed in an office building, and mentioned the need for the improvement of the coefficient of performance (COP) and seasonal energy efficiency ratio (SEER) for the system for their long-term operation; Zhu et al. [15] evaluated the electricity and water efficiency of a new ground water source heat pump system under improved operation methods during the summer (June to September) and winter (November to February) seasons.

However, most of these studies are experimental or theoretical investigations of water source heat pumps. The effect of the adoption of these systems, which are mostly employed in new buildings, on energy and greenhouse gas emissions is merely hypothetical. The heating and cooling systems employed in buildings in previous studies use water as the energy source, transported from a man-made well or bore located near the building to be serviced or in the local area. But in reality, it is not easy to find enough space for these man-made structures, especially for existing buildings and in high-density cities consuming considerable amounts of energy, and recently the effect of drilling on earthquakes is being debated after larger and more frequent earthquakes have been noticed in Korea. To maximise the economic and environmental aspects these systems are recommended to use natural elements when considering the building and its surrounding environment, and to exclude man-made elements as much as possible.

3. Research Methods

The main objective of this paper is to investigate the feasibility of employing the unused water in urban areas as an energy source for heat pump systems. The study analyses the energy savings generated by a sustainable heating and cooling system that operates with underground water escaping from the pipelines in a nearby subway station, in comparison with the system that it replaced. The building characteristics are also reviewed in terms of their system efficiency.

A number of articles have used various simulation tools to predict the energy consumption of buildings to evaluate the potential efficiency and effectiveness of energy reduction [16]. In this study, the efficiency and effectiveness analysis is based on the actual energy use before and after the adoption of a sustainable energy system. The selected case studies are Korea university academic buildings located near a subway station, and they use water escaping from the pipelines of the subway station as a source for a geothermal heat pump. We first carried out a site inspection in order to understand the factors influencing energy consumption, such as building-related characteristics and their mechanical and electrical systems. Operational information was supplemented by interviewing the facility managers before starting the energy data analysis. The energy use for each building was compiled from metering data, building survey data and statements issued by utility companies on monthly basis over the period from January 2011 to December 2014 and January 2015 to December 2015.

4. A Case Study of Geothermal Energy and Water Sources in a University

4.1. Building Characteristics

As shown in Table 1, the buildings studied (Building A and B) face southeast and are located near a subway station in an adjoining street. The total floor area of each building is about 14,390 m^2. The buildings have a reinforced concrete frame with granite infill walls, and one side of Building B is glass, in the form of 24 mm double-glazed windows. Both buildings were built after 2001, the year in which the energy efficiency requirements in the building code were improved significantly [17].

Both are humanities buildings, and thus do not house laboratory equipment, which is a large consumer of electricity and LNG, and both are heavily used for academic studies. Building A houses the Faculty of Business Administration, and Building B hosts various disciplines (including the Faculty of Education, the Institute of Continuing Education, the Korean Language Centre, etc.) with ancillary facilities comprising 8% of the total floor area. Within both buildings the following main spaces were included: classrooms, study facilities, office facilities and general use facilities such as auditoriums, seminar rooms, meeting rooms, lounges and any multi-function rooms. Among these facilities, it is the classrooms and general use facilities that determine the operations of a central heating and cooling system with different daily schedules related to room activities. The operating hours for all other spaces are from 8.00 a.m. to 6.00 p.m. in summer and 7.00 a.m. to 8.00 p.m. in winter on weekdays [17].

Table 1. The two case study buildings.

	Location	Direction	Building Type	Year Built	Total Floor Area	Materials	System Operation
Building A Building B	Humanities campus, Korea university	SE	Academic	Early 2000s	~14,390 m^2	Reinforced concrete structure, granite, double-glazed windows	Central heating and cooling

4.2. The Heating and Cooling System

The existing LNG-based absorption chiller-heaters (two 706.0 kW in Building A and two 882.5 kW in Building B, thermal efficiency 80%) were replaced with a new system including a geothermal and water source (which were being previously dumped in the nearby river) heat pump designed with a capacity of 2118 kW, obtaining a COP of about 4.0 for cooling and 3.4 for heating, through a building retrofit project promoted by the Seoul Metropolitan Government in the second quarter of 2014. The new system comprises several items of equipment, including the heat pump, steam boiler, heat exchanger (for heat recovery and in the boiler), circulating and supply pump, feed water pump, underground water tank, buffer tank and closed type expansion tank, as shown in Figure 1. To operate this system, approximately 1500 m^3 water escaping from the pipelines of Anam subway station on the site, corresponding to more than half (60.5%) of the total daily inflow, is pumped and stored in a machine room on the first floor of Building B each day. Previously, this water was discharged through a manhole at the surface and drainage to a stream. The water temperature is 15–19 degrees Celsius for the cooling season and 14–17 degrees Celsius for the heating season (which is appropriate for an energy source), and it has passed water quality criteria for residential purposes [6]. Low water levels in the dry and cool season can reduce pumping capacity, but this system has not experienced any difficulty yet; the water volume is adequate to operate the system.

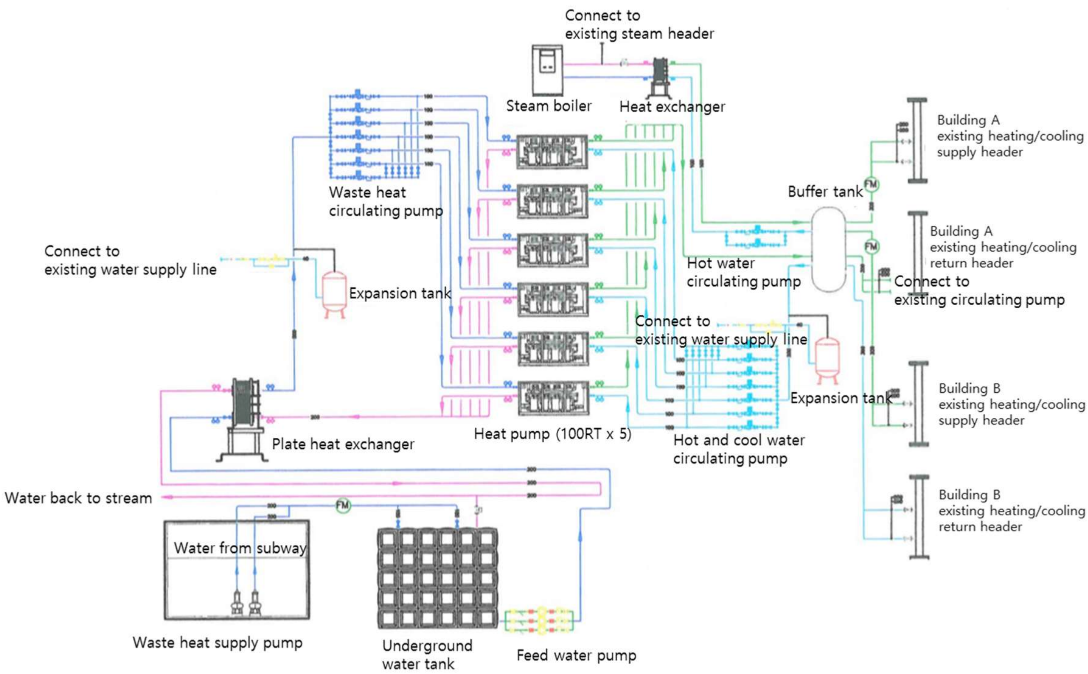


Figure 1. Schematic of the ground water source heat pump system.

4.3. Energy Consumption before and after Replacing the Heating and Cooling System

Figure 2 shows the total annual energy usage of the entire campus and the studied buildings over a six-year period (2011–2015), excluding 2014, when the system was replaced, as mentioned above. The average values of annual energy consumption before 2014 were 474.4 ton of oil equivalent (TOE) for Building A and 397.5 TOE for Building B. The energy consumption in the buildings studied has either declined or grown irregularly over the period, in contrast to the steady decline in total energy use on the campus, as shown in Figure 2a. However, from 2013, following an energy efficiency retrofit project that improved the lighting system and implemented an integrated automatic control system from July 2012, only a slight decline is evident. In terms of energy sources, electricity consumption is changing at a greater rate, leading to the increase in total energy consumption, while LNG consumption has not changed significantly, as demonstrated by Airaksinen [18]. In 2011 in particular, Building A's electricity consumption rose by about 40% and, in turn, the campus total energy consumption rose dramatically (approximately 30%), reaching a maximum value of approximately 560 TOE. The annual electricity consumption of Buildings A and B ranges from 421 to 292 TOE and from 345 to 288 TOE, respectively, and the LNG consumption of Buildings A and B ranges from 155 to 137 TOE and from 91 to 75 TOE, respectively.

In 2015, a clear decrease to almost zero (5.6 TOE for Building A and 3.4 TOE for Building B, which consume LNG only for supplying hot water) was seen in LNG consumption due to the replacement of the existing LNG-based absorption chiller-heater with a geothermal and water source heating and cooling system. On the other hand, electricity use decreased 0.6% and increased 14.9% (consuming 327.6 TOE for Building A and 361 TOE for Building B) than the average value of 2010–2013. In summary, the energy usage of Buildings A and B decreased by 29.8% and 8.2% (energy consumption was 333.3 TOE and 364.8 TOE in 2015), respectively, and in turn, energy-related carbon dioxide emissions also decreased by 30.4% and 8.8%, respectively. Building energy use for heating, cooling, lighting, ventilation and hot water varies depending on factors such as building- or user-related characteristics. Many researchers have conducted investigations to understand the interconnection between these factors and their effect on energy consumption [19]. The university is an excellent case study to assess the effects of energy savings as a result of system improvements to its buildings, which are managed system by the same entity under uniform standards [20]. The occupancy and space usage of each building are little different annually, although the university has various types of buildings that afford different space uses and schedules. Therefore, the total energy reduction shown above can be defined as the effect of replacing the heating and cooling system for Buildings A and B.

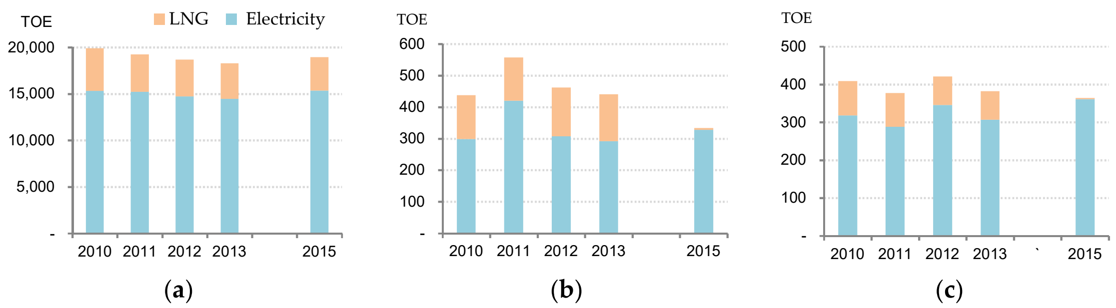
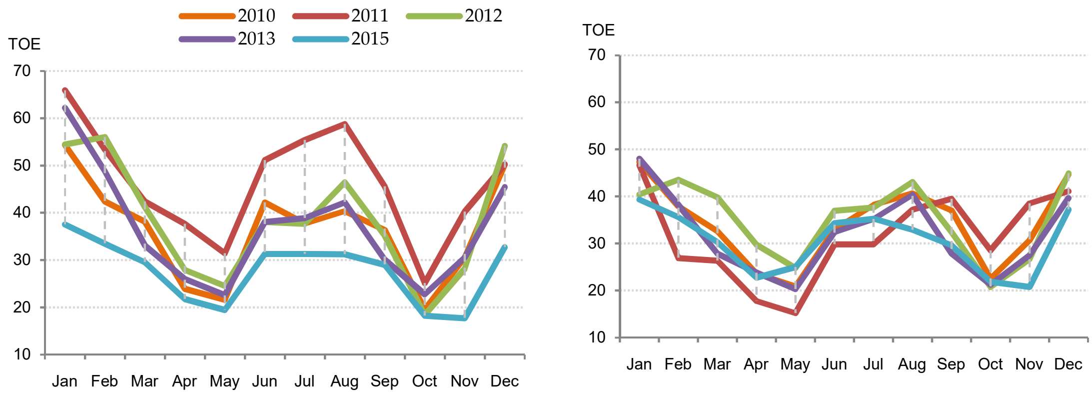


Figure 2. Energy consumption before and after 2014: (**a**) Entire campus; (**b**) Building A; (**c**) Building B.

Seoul has dry winter months (e.g., December, January, and February) and humid summer months (e.g., June, July, and August). During those periods a large amount of energy consumed in building, and the energy use is directly related to climate change [21] and continually increasing with renewing record of the lowest and highest temperature [22]. Figure 3 sets out the monthly energy consumption of the studied buildings before and after 2014. The energy use for heating and cooling has a significant impact on total energy consumption. The data also shows that the energy use in university buildings has changed depending on academic calendar. For example, the energy consumption of the building incurring the peak electricity load during the coldest and hottest months does not significantly increase compared to other types of buildings (e.g., commercial and residential buildings in the area) due to academic circumstances and activities such as school holidays. Figure 3a shows energy consumption reduction of Building A with system replacement in year 2015. All in all, it is greatly changed in all heating and cooling seasons, especially during winter period. The heating and cooling usages decline 52.2% and 40.3% (or about 30% excepting year 2011 increased cooling usage significantly) from the average of year 2010–2013 respectively. On the other hand, Building B has little or no change in cooling usage (excepting August), although heating usage declines slightly as shown in Figure 3b.

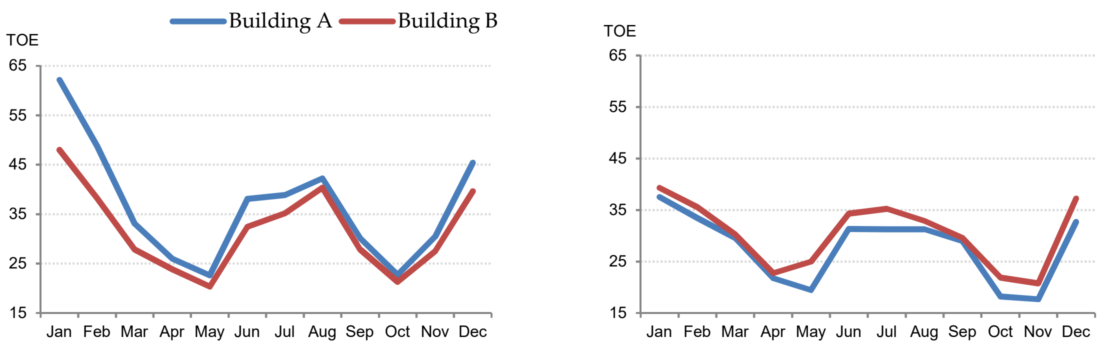


(**a**) (**b**)

Figure 3. Monthly energy consumption before and after 2014: (**a**) Building A; (**b**) Building B.

We compared the energy consumption of Buildings A and B for 2013, which was closest to the average energy consumption of the years 2010–2013, and 2015, as shown in Figure 4a,b, respectively. In 2013, Building A's energy consumption was always higher than that of Building B, but after the heating and cooling system was replaced this was reversed. The result is more clearly shown in terms of changes in the monthly energy use of each building.

Although the minimum required energy shows little change, the maximum required energy was greatly reduced, especially during the cooling season (an approximately 30–40% reduction; e.g., 62.18 TOE in December 2013 and 37.53 TOE in December 2015) for Building A. However, energy use in Building B is increasing, rather than declining, during most of the semester months, and so the change is irregular. We conjecture that this is due to the fact that Building B hosts lectures for graduate students over weekends and/or at night, and well as many events, such as conferences.



(**a**) (**b**)

Figure 4. Monthly energy consumption comparison: (**a**) Year 2013; (**b**) Year 2015.

The peak load per unit heating and cooling surface area is calculated by considering factors influencing building energy consumption, and hence its value can be used as an energy performance indicator. Building A is more energy efficient than Building B, as shown in Table 2. Judging from the values of the energy consumption, as mentioned before, and the peak loads, there is a significant relationship between building energy performance and energy consumption changes following the heating and cooling system replacement in 2014. The heating peak load difference in particular is more than double, and the energy reduction achieved by replacing the system is almost threefold during the heating season. That is, the building performance has a significant impact upon energy consumption and CO_2 emission change after the retrofit.

Table 2. Daily and monthly peak loads (W/m^2).

Area		Daily Peak Load	Monthly Peak Load
Building A	Cooling	63.74	56.63
	Heating	56.81	43.96
Building B	Cooling	103.82	94.18
	Heating	123.52	104.15

5. Conclusions

The use of currently unused, but potentially valuable, renewable energy resources in the Republic of Korea has been substandard, with the majority of this being via waste incineration. However, in terms of environmental protection the possibility of utilising sustainable energy resources needs to be reviewed, particularly in our current environment. Underground water may be useful as a source of temperature difference energy in urban areas, which consume considerable amounts of energy (e.g., for space heating and cooling, as analysed in this paper). This paper analysed the effects of a sustainable heating and cooling system using underground water escaping from subway pipelines as a source for a heat pump designed to reduce fossil fuel use. By comparing energy use before and after the adoption of this sustainable energy system, it was found that the energy consumption of Buildings A and B decreased by 29.8% and 8.2%, respectively, due to a significant reduction in peak demand as well as in total energy consumption, and a concomitant decrease in energy-related carbon dioxide emissions to about 40%. This reduction is the result of replacing the existing heating and cooling system, regardless of the energy use for lighting, ventilation and hot water, since unlike other building types, the energy use of university buildings that are managed by the same entity under a uniform standard is almost constant over the years. From this result, we also deduce that energy efficient buildings further reduce energy consumption (over 20% difference compared to the energy performance of the buildings studied here). Although our results show quite different potential energy saving depending on building energy performance, there is value in protecting the environment.

In recent years the Seoul Metropolitan Government has been heavily promoting a building retrofit project, and the Ministry of Trade, Industry, and Energy is also showing interest in this system, which utilizes underground water escaping though pipelines in subway stations as a solution to reduce carbon dioxide. Therefore, this study has wider significance for implementing unused energy resource research in system applications in buildings. For more detailed planning in response to government-designed greenhouse gas and energy reduction targets, further analysis of systems operations is required in the future.

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