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Article

Economic Feasibility Analysis of the Application of Geothermal Energy Facilities to Public Building Structures

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Abstract: This study aims to present an efficient plan for the application of a geothermal energy facility at the building structure planning phase. Energy consumption, energy cost and the primary energy consumption of buildings were calculated to enable a comparison of buildings prior to the application of a geothermal energy facility. The capacity for energy savings and the costs related to the installation of such a facility were estimated. To obtain more reliable criteria for economic feasibility, the lifecycle cost (LCC) analysis incorporated maintenance costs (reflecting repair and replacement cycles based on construction work specifications of a new renewable energy facility) and initial construction costs (calculated based on design drawings for its practical installation). It is expected that the findings of this study will help in the selection of an economically viable geothermal energy facility at the building construction planning phase.

Keywords: economic analysis; geothermal energy; lifecycle cost; public building

1. Introduction

Demand for improvements in quality of life, as well as for various benefits necessitates the provision of a consumer-centred construction environment, even within the building sector. To satisfy consumer demands related to indoor and outdoor environments, a construction environment system should accommodate both natural and artificial controls. To accomplish this end, an optimal building structure should be built in composite harmony with construction plans, the latter including the facility system plan, the spatial plan and the structural plan. Interest in reducing greenhouse gas emissions arising from energy demand within building structures has gradually been increasing, this being a component of optimal building structure; however, there are technical limitations to the extent to which energy consumption can be reduced simply by maximizing the efficiency of fossil energy in conventional use. One of the approaches to addressing this problem is to reduce fossil fuel consumption using new renewable energy resources [1]. To fundamentally increase the efficiency of energy consumption, there is thus an urgent need to develop new technologies that can utilize these eco-friendly renewable energy resources [2].

The EU stipulates that all new building structures to be built from 2019 onwards must produce more energy than they consume; similarly, with a view toward achieving zero-energy buildings by 2025, compulsory regulations and obligatory expansion plans have been established in the U.S. [3]. Other advanced countries have likewise made efforts to expand new renewable energy facilities and increase the supply ratio. In line with this trend, Korea has also made efforts to increase the supply ratio of new renewable energy from the fairly low level of 1.6% in 2012. For these reasons, planning for energy consumption capacity and savings should start at the construction project planning phase.

Geothermal power is cost effective, reliable, sustainable and environmentally friendly. It is also available 24 hours/day which can be used as the base load. Historically, it has been limited to areas near tectonic plate boundaries. However, recent technological advances have dramatically expanded the range and size of this source, especially for applications, such as home heating, opening a potential for widespread exploitation, as has been described in this study. In this study, the geothermal system, a renewable energy facility applied to multiple building structures, was employed to analyse relative reductions in energy consumption and energy use cost and to determine the energy savings cost related to the use of this system in consideration of the lifecycle cost (LCC), which includes initial investment costs, repair and replacement cycles for major materials. The ultimate aim is that of proposing an effective plan for geothermal system selection at the construction project planning stage through economic feasibility analysis.

2. Methodology

This study is limited to the application of new renewable energy to a building structure with geothermal facilities, based on statistics and on previous studies. The target buildings selected for this research were three public buildings, within which the installation of a new renewable energy facility is compulsory. In all cases, the renewable energy facility, which varies in size across the three buildings, had already been designed. By analysing the design data of the buildings, the volume of new renewable energy was converted into that of the energy applied to the conventional energy facility, and the buildings were modelled with no application of the new renewable energy source. Using total energy consumption evaluation program (ECO2-OD), the compulsory supply volume of new renewable energy was calculated, and geothermal facility installation sizes in the proportions of 100% and 25% of compulsory supply volume, respectively, were set and applied in each case.

Energy consumption and primary energy consumption of the building structures were calculated to perform a comparative analysis of changes related to the application of the geothermal energy system and to determine the changes in the energy volume used. A comparative analysis of the economic feasibility of geothermal energy application was conducted between buildings with geothermal facilities and those without, based on reductions in energy cost. The initial construction cost was applied, together with the cost of the redesigned specification for buildings with geothermal facilities. Where the volume of the conventional energy facility was replaceable, the volume change of the conventional facility resulted from the application of the geothermal facility, and the removal of the facility was reviewed and reflected in the initial investment cost. The useful life was set at 40 years in the LCC analysis; the analysis cycle was set at 10 years, and the repair and replacement cycles of major materials were chosen to ensure the reliability of maintenance cost calculations.

3. Literature Review

Many studies on the application of new renewable energy facilities to building structures have been conducted, through which plans have also been proposed to improve the reliability and economy of such applications. Rezaie *et al.* [4] divided case buildings by usage to analyse the economy, efficiency and energy emission of geothermal, solar-powered, photovoltaic and hybrid power systems. Visa *et al.* [5] studied the energy state required before and after the installation of a photovoltaic energy system in terms of efficiency and economic feasibility and performed an analysis of the latter. Cucchiella *et al.* [6] conducted a performance evaluation of a photovoltaic energy system installed in building structures to analyse the time required to retrieve investment cost and the extent of influence of climate and the energy consumption behaviour of residents within the area of installation. Francisco and Batlles [7] conducted a comparative analysis between a cooling system that applied photovoltaic energy and a conventional system and predicted the rate of reduction in energy consumption capacity as an alternative to reducing energy consumption. Similarly, many studies have been actively conducted to examine the utilization of new renewable energy resources in different countries in order to reduce energy consumption. However, there are no clear-cut criteria for the selection and application of such renewable energy facilities at the building structure planning phase, and it is difficult to select a facility that will achieve effective energy savings and secure economic feasibility. Furthermore, the determination of a new renewable energy system for building structures should occur at the planning and design phases, and its applicability and characteristics need to be taken into account, because the energy source may vary depending on the appearance and use of a building structure.

Previous studies performed in Korea can be subdivided into two categories—those examining the current state and application of new renewable energy within building structures and energy production volume and economic feasibility analyses of new renewable energy sources. Jung *et al.* [8] proposed a process to integrate a new renewable energy system into a construction design factor to enable the application of new renewable energy; the authors analysed systems according to their characteristics to apply and analyse applicable new renewable energy systems depending on the design process. Kang *et al.* [9] analysed the building energy substitution rate for public buildings in which 5% of the total construction cost was invested into the installation of a new renewable energy facility and presented a plan for efficiency improvement with no additional cost, using such a facility. As a component of the fundamental data to develop plan criteria for the application of a new renewable energy system to building structures, Kim *et al.* [10] proposed a direction for domestic construction planning based on an analysis of building structures that apply new renewable energy in Korea and Germany, focusing on photovoltaic and geothermal energy. Yoon *et al.* [11] suggested an option for the development of a new renewable energy planning tool that reflects various requirements, including the supply ratio of new renewable energy, the selection of a system type, the time of application and the method. Seo *et al.* [12] derived an optimal application plan by researching the current state of new renewable energy penetration and reviewing alternatives for an efficiency improvement plan according to changes in the volume of conventional new renewable energy systems. In addition, reviews of energy production volume and economic feasibility relating to new renewable energy resources applied to building structures have been actively conducted. Kim and Kim [13] carried out economic feasibility evaluations of photovoltaic, wind, small hydro and bio-gas power systems and presented a new renewable energy application plan. Kim *et al.* [14] performed an LCC analysis of the application of new renewable energy to reduce energy consumption and to analyse the energy-saving effect resulting from the reduction in the energy consumption cost and the retrieval period of the initial investment cost upon application of the new facility; the authors also proposed a scheme for economic building structure planning. Lee *et al.* [15] conducted an analysis of energy intensity by building use based on an analysis of the actual state of energy use in public office facilities, with the enforcement of the law compelling the installation of new renewable energy facilities within public organizations. However, assessments conducted in previous studies have addressed the future applicability of new renewable energy sources at the level of fundamental data by exploring the current state of new renewable energy use, the actual state of management and its problems and user satisfaction; the limitation of these studies thus lies in the lack of understanding of a direction to improve the management of a new renewable energy system. In addition, there are no concrete analysis processes and criteria for the analysis of energy production volume and economic feasibility, and a cyclical analysis of the entire lifecycle of building structures has not been performed, resulting in many limitations to actual applications of resolutions. The summary of previous studies is listed in Table 1.

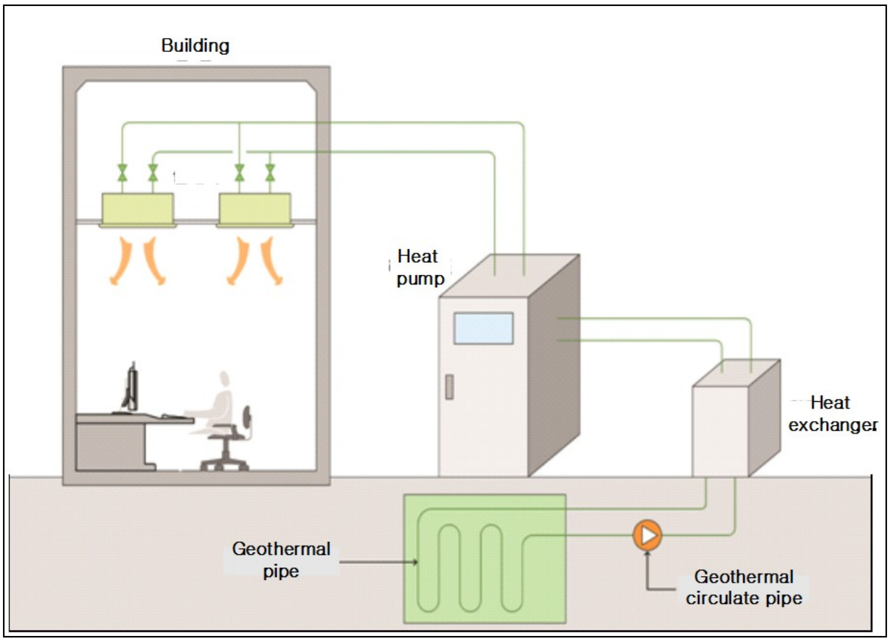
Table 1. The summary of previous studies. LCC, lifecycle cost.

Authors	Year	Research Aim
Jung *et al.*	2008	Applying and analysis of a new renewable energy design process
Kim & Kim	2008	Presenting a new renewable energy application plan
Rezaie *et al.*	2011	Analysis of energy emission quantity based on renewable energy options
Kang *et al.*	2011	Analysis of renewable energy and building energy substitution rate
Kim *et al.*	2011	LCC analysis of the application of new renewable energy to reduce energy consumption
Cucchiella *et al.*	2012	Performance evaluations of integrated photovoltaic systems
Lee *et al.*	2012	Analysis of energy intensity by building use based on the actual state of energy use
Kim *et al.*	2012	Applying new renewable energy focusing on photovoltaic and geothermal energy
Francisco & Batlles	2013	Forecasting energy savings rate by applying solar energy
Yoon *et al.*	2013	Suggesting an option for the development of a new renewable energy planning tool
Seo *et al.*	2013	Improvement plan according to changes in volume of conventional new renewable energy
Visa et al.	2014	Economic analysis of the renewable energy mix in a building

4. The Geothermal System

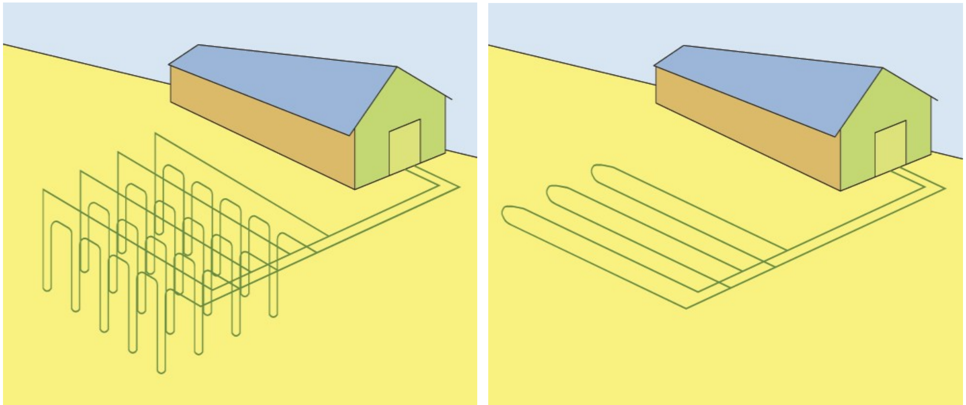
A geothermal system uses geothermal heat to achieve an increase in temperature, with the latter maintained at a certain level deeper than 15 m below the surface of the Earth, regardless of atmospheric temperature. Geothermal energy can be largely subdivided into geothermal and land surface heat. Geothermal heat is heat energy continuously generated by the decay of radioactive isotopes in the core of the Earth, *i.e.*, the energy that magma emits toward the surface of the Earth. Land surface heat can be classified as shallow or deep geothermal heat depending on depth below the surface of the Earth [16]. Shallow geothermal heat averages 5–20 °C at less than 15 m from the surface of the Earth. To use shallow geothermal heat, a 100- to 300-m-deep borehole is drilled to lay a geothermal heat exchanger, which provides energy to a building structure for heating and cooling using a heat pump and an air handling unit, as shown in Figure 1. In the case of deep geothermal heat, the Earth is excavated to 3 km below the ground to obtain steam with a temperature of 65 °C or higher to generate electricity through a steam turbine [17]. A geothermal system for cooling in summer operates as follows: the high temperature and high pressure cooling gas compressed by the compressor of a heat pump exchanges heat at the geothermal heat exchanger, with conversion into a moderate temperature and high pressure liquid, resulting in cooling effects when the liquid evaporates in the indoor evaporator at low temperature and in a low pressure state through expansion in the expander. On the other hand, in winter, the geothermal heat pump system works in the opposite direction, absorbing geothermal heat and supplying it to the inside of a building [18].

Figure 1. The structure of a geothermal system.



Geothermal systems can be broadly categorized as either open or closed, depending on the circuit composition of the heat exchanger that collects the geothermal heat. An open loop system is one in which the pipe that carries water supplied from phreatic and underground sources is applied to locations within a basin with effluent water. A closed loop system is one in which water circulates within the pipe to collect (exchange) geothermal heat. Closed loop systems are classified as vertical or horizontal based on the loop type, as shown in Figure 2. The vertical type ranges from 100–150 m below ground, while the horizontal type ranges from 1.2–1.8 m below ground.

Figure 2. Vertical (**left**) and horizontal (**right**) types of closed loop systems.



5. Case Analysis of Energy Consumption Capacity by Building Structure

The following are to be determined for the analysis of energy consumption: (1) general information for each case and the major energy load factors for energy consumption calculation; (2) the total annual energy consumption for cases in which no new renewable energy facility is applied, the energy consumption cost and annual consumption by unit area, the consumption cost and primary energy consumption; (3) the total annual energy consumption for cases where a geothermal energy facility is applied; (4) a comparative analysis of energy consumption and consumption cost and the total annual energy consumption for each case, considering examples with and without a geothermal energy facility; and (5) the energy-saving effects and cost savings resulting from the application of a geothermal energy facility for all cases and the energy consumption and energy consumption cost by the scale of the building structure following the application of the geothermal facility.

As shown in Table 2, three public office buildings of a similar size, all of which are subject to compulsory installation of a new renewable energy facility, were selected as the target cases to be analysed. The location of all cases is a central city of South Korea. Energy consumption and energy consumption costs were analysed for each building; subsequently, the same parameters were measured following the application of a geothermal energy system, for use in calculating and analysing the LCC of the buildings.

Table 2. The description of an electric heat pump (EHP).

Description		Case 1	Case 2	Case 3
Type of cases		Public building		
Structure		Reinforced concrete		
Size of building	No. of floors	Basement floor = 1, Ground floors = 3		
	Building areas	774.42 m^2	1495 m^2	2786.57 m^2
	Total areas	1997.83 m^2	4006.58 m^2	12,690.79 m^2
Heating and air-conditioning areas		1421.58 m^2	2699.4 m^2	7292.16 m^2
Outer wall area/window area		20.45%	18.81%	32.67%

Table 2. *Cont.*

Description		Case 1	Case 2	Case 3
Type of cases		Public building		
Structure		Reinforced concrete		
Main energy facilities	Heating (kW)	EHP: 339.6	EHP: 420.1	EHP: 2358
	Air-conditioning	EHP: 301.6 kW	EHP: 377 kW	EHP: 2289.6 kW
	Hot-water supply (kW)	Gas boiler: 41.86	Lamp oil boiler: 116.28	Gas boiler: 244 kW × 2
	Ventilation (kW)	Exhaust fan lamp: 6.706	Exhaust fan lamp: 5.47	Air-conditioning equipment lamp: 35.72
	Lighting	6.64 W/m^2	8.02 W/m^2	8.00 W/m^2

6. Analysis of Energy Consumption and Cost

Table 3 shows the total annual energy consumption and cost for each case, calculated using ECO2-OD. Total annual energy consumption and cost, which were compared across cases following the application of the geothermal energy facility, were calculated based on heating, cooling and hot-water supply calculated in consideration of cooling and heating areas and lighting and ventilation calculated in consideration of gross floor area and the sum total. In terms of consumption cost, the basic rate for contract electricity capacity applied to each building is fixed, and this was not included in the analysis of consumption cost. In the analysis of total annual energy consumption and consumption cost, the area to which individual energy load is applied was calculated by multiplying each cooling and heating area, while the lighting and ventilation load were calculated by multiplying gross floor area. There were therefore differences in total energy consumption capacity and consumption cost. For this reason, it was hard to set evaluation criteria for the comparison of each case, and this data was not utilized for comparisons; this aspect would, however, comprise a significant calculation variable for the application of a new renewable energy facility.

Table 3. Annual energy demand quantity and use of cases.

Description		Case 1	Case 2	Case 3
Energy demand quantity (kWh/year)	Heating	68,981.18	118,053.14	365,861.47
	Air-conditioning	26,977.01	60,118.07	201,622.22
	Hot-water supply	18,091.80	35,867.80	66,520.70
	Lighting	31,160.87	75,762.22	238,485.33
	Ventilation	31,155.86	12,350.45	145,950.22
	Total	176,366.72	302,151.68	1,018,439.93
Energy use cost (Won/year)	Heating	6,044,821	11,415,739	35,378,804
	Air-conditioning	2,363,995	5,813,417	19,496,869
	Hot-water supply	1,440,518	4,040,650	5,264,658
	Lighting	2,730,627	7,326,207	23,061,531
	Ventilation	2,730,188	1,194,289	14,113,386
	Total	15,310,149	29,790,302	97,315,248

The cost of the LCC of CO_2 ($LCCO_2$) emission can be estimated by multiplying the required material cost of a component with the CO_2 emission basic units of the identified major construction materials. The multiplied cost should be converted into the current market-traded CO_2 emission price. As mentioned earlier, there are various markets for trading emission rights with the intention of controlling air pollution in developed countries. Among various markets, the price of the EU Allowance (EUA), which is traded in the European telecommunication standards, is adopted to calculate the $LCCO_2$, and the average price of CO_2 emissions (from 2005 to 2009), as suggested by European climate exchange, is applied. The average price is 19.73 EURO/ton. In addition, the average Euro:Won exchange rate in 2009 is applied, which is the standard currency in the ECX.

7. Analysis of Energy Consumption Capacity and Cost in the Application of a Geothermal Energy Facility

Following the application of a geothermal energy facility, the energy capacity by facility was estimated based on calculations of geothermal energy production capacity equivalent to 11% of the expected energy consumption capacity of a building structure, with a compulsory supply rate for 2013 of 100% and 25% of geothermal system capacity. The calculation order of geothermal energy installation capacity was as follows: (1) the expected energy consumption capacity of the target building was calculated; (2) the geothermal energy production capacity was estimated by multiplying the compulsory supply rate by the expected energy consumption capacity; (3) the energy production capacity per unit capacity was estimated by multiplying unit energy production capacity by geothermal energy with the application of a modification factor; and (4) installation capacity was calculated by dividing the geothermal energy production capacity by the energy production capacity per unit capacity by geothermal energy. The geothermal energy production capacity is thus a modified value of energy capacity produced annually using a geothermal energy facility, and the expected energy consumption capacity is the expected annual energy consumption capacity.

The expected energy consumption and geothermal energy production capacities were estimated by applying 371.66 (kWh/m^2/year) for unit energy consumption capacity and 1.73 for the modification factor by use. The applied locality coefficients were 0.99 in Case 1 (Gyeonggi region), one in Case 2 (Daejeon region) and 0.98 in Case 3 (Gyeongbuk region). The installation capacity actually selected based on the above process was applied to estimate expected energy consumption capacity, taking the dimensions and formations of each facility into account. Geothermal energy production capacity was calculated by applying 11% of the expected consumption capacity, the compulsory supply rate. The standard capacity represents the capacity of a geothermal energy facility required to satisfy the geothermal energy production capacity. Table 4 shows the application capacity of geothermal energy facilities by region.

Table 4. Geothermal energy application capacity of cases.

Case 1	Anticipated energy usage	1,271,703 kWh/year
	Geothermal energy production	139,887 kWh/year
	Standard capacity	99.00 kW
	100% installation capacity of standard capacity	105.80 kW
	25% installation capacity of standard capacity	25.65 kW

Table 4. *Cont.*

Case 2	Anticipated energy usage	2,524,596 kWh/year
	Geothermal energy production	277,706 kWh/year
	Standard capacity	194.00 kW
	100% installation capacity of standard capacity	208.38 kW
	25% installation capacity of standard capacity	53.80 kW
Case 3	Anticipated energy usage	8,159,820 kWh/year
	Geothermal energy production	897,580 kWh/year
	Standard capacity	628.00 kW
	100% installation capacity of standard capacity	658.80 kW
	25% installation capacity of standard capacity	167.20 kW

Case 1, which appeared to have the best average heat transmission value for the external wall of 0.619 W/m^2 K (K: heat transmission coefficient) in the basic insulation standard, used electricity as the energy source, with the exception of hot-water facilities, which relied on an urban gas boiler. When applying 100% of the standard capacity, a higher level of cooling energy consumption was achieved compared to the application of 25% of the standard capacity. This may be because the power of the circulation pump for geothermal exchange is greater than that of other cooling load facilities, due to its relatively large size. For the total cooling capacity of the EHP, 191.4 kW was applied, with 3.75 kW for the consumption power of auxiliary devices, 105.8 kW for geothermal heat and 4.4 kW for the circulation pump. Table 5 shows the total annual energy consumption capacity and consumption cost of the geothermal energy facility by region, specifically for Case 1.

Table 5. Annual total energy demand quantity and use cost of Case 1.

Description		100% application of standard capacity	25% application of standard capacity
Energy usage (kWh/year)	Heating	59,109.30	66,188.76
	Air-conditioning	25,062.46	23,868.33
	Hot-water supply	18,096.71	18,096.71
	Lighting	31,166.15	31,166.15
	Ventilation	31,146.17	31,146.17
	Total	164,580.78	170,466.12
Energy use cost (Won/year)	Heating	5,179,748	5,800,121
	Air-conditioning	2,196,223	2,091,582
	Hot-water supply	1,440,909	1,440,909
	Lighting	2,731,090	2,731,090
	Ventilation	2,729,339	2,729,339
	Total	14,277,308	14,793,041

The reduction rate of the annual energy consumption capacity and the cost in the case of 100% compulsory installation capacity were shown to be 7.44% and 7.52%, respectively, when compared with cases where no geothermal energy facilities were present. The reduction rate in geothermal heat in the case of 25% compulsory installation capacity was shown to be 50% of the level of 100%

compulsory installation capacity, indicating that when applying a geothermal system, differences may arise from different capacities of the geothermal circulation pump, which is known to be the primary cause of power consumption. The circulation pump in the geothermal system is running continuously, and its application capacity is determined depending on geothermal installation capacity. When a large capacity is loaded, the value increases, but the rate of increase is not proportionate to the installation capacity. The selection of an appropriate capacity for the circulation pump of a geothermal system is therefore considered to be a factor that can improve energy efficiency in the application of such a system.

The energy consumption per unit area is used as a criterion for the calculation of total energy consumption, but the gross floor area is used to calculate the lighting and ventilation load, while the cooling and heating areas are used to calculate the hot-water supply load. For this reason, the total energy consumption capacity may differ depending on the ratio of cooling and heating areas over the gross floor area. However, the consumption capacity per unit area shows the energy reduction effect of the applied geothermal energy facility regardless of the entire building structure and can be used as a good criterion for the evaluation of these facilities. Annual energy consumption capacity and cost per unit area are indicated in Table 6. Table 7 provides a comparison of the total annual energy consumption and cost.

Table 6. Annual energy demand quantity per unit area and use cost of cases.

Description			100% application of standard capacity	25% application of standard capacity
Case 1	Energy usage	Does not apply	111.42	
		Apply	103.13	107.27
		Reduction capacity	8.29 kWh	4.15 kWh
		Reduction rate (%)	7.44	3.72
	Use cost	Does not apply	9662	
		Apply	8935	9298
		Reduction capacity	727 Won	364 Won
		Reduction rate (%)	7.52	3.77
Case 2	Energy usage	Does not apply	101.28	
		Apply	91.15	99.70
		Reduction capacity	10.13 kWh	1.58 kWh
		Reduction rate (%)	10.00	1.56
	Use cost	Does not apply	10,007	
		Apply	9,027	9,854
		Reduction capacity	980 Won	153 Won
		Reduction rate (%)	9.79	1.53
Case 3	Energy usage	Does not apply	117.23	
		Apply	108.68	113.95
		Reduction capacity	8.55 kWh	3.28 kWh
		Reduction rate (%)	7.29	2.80
	Use cost	Does not apply	11,177	
		Apply	10,349	10,858
		Reduction capacity	828 Won	319 Won
		Reduction rate (%)	7.41	2.85

Table 7. Annual energy demand quantity and use of cases.

Description			100% application of standard capacity	25% application of standard capacity
Case 1	Energy usage	Does not apply	176,366.72	
		Apply	164,580.78	170,466.12
		Reduction capacity	11,785.94 kWh	5,900.60 kWh
		Reduction rate (%)	6.68	3.35
	Use cost	Does not apply	15,310,149	
		Apply	14,277,308	14,793,041
		Reduction capacity	1,032,841 Won	517,108 Won
		Reduction rate (%)	6.75	3.38
Case 2	Energy usage	Does not apply	302,151.68	
		Apply	274,793.40	297,873.27
		Reduction capacity	27,358.28 kWh	4,278.41 kWh
		Reduction rate (%)	9.05	1.42
	Use cost	Does not apply	29,790,302	
		Apply	27,144,843	29,376,666
		Reduction capacity	2,645,459 Won	413,636 Won
		Reduction rate (%)	8.88	1.39
Case 3	Energy usage	Does not apply	1,018,439.93	
		Apply	956,066.67	996,005.34
		Reduction capacity	62,373.26 kWh	22,434.59 kWh
		Reduction rate (%)	6.12	2.20
	Use cost	Does not apply	97,315,248	
		Apply	91,283,753	95,145,822
		Reduction capacity	6,031,495 Won	2,169,426 Won
		Reduction rate (%)	6.20	2.23

Table 8 shows annual primary energy consumption per unit area by new renewable energy facility. Geothermal heat ranked higher in the category of annual primary energy consumption per unit area, which resulted from employing kerosene with an energy conversion factor of 1.1 for hot-water supply as the energy source.

Table 8. Annual primary energy demand quantity of cases.

Description			100% application of standard capacity	25% application of standard capacity
Case 1	Energy usage	Does not apply	293.41	
		Apply	270.61	281.98
		Reduction capacity	22.80 kWh	11.43 kWh
		Reduction rate (%)	7.77	3.90
Case 2	Energy usage	Does not apply	244.91	
		Apply	212.60	240.83
		Reduction capacity	32.31 kWh	4.08 kWh
		Reduction rate (%)	13.20	1.67
Case 3	Energy usage	Does not apply	307.98	
		Apply	284.46	298.93
		Reduction capacity	23.52 kWh	9.05 kWh
		Reduction rate (%)	7.64	2.94

The comparison of energy consumption and cost per unit area cannot be perfect, due to differences in equipment characteristics, such as the installation situation of the energy load facility and architectural characteristics, such as window area rate and the insulation performance of walls. However, it can be used as a reference for selecting an appropriate geothermal facility for a building structure, through a comparison of cases of different scales that are characterized as having similar energy consumption at a certain level and which do not require the application of cooling and heating areas. The effect of geothermal heat was shown to be best when applying 100% of the standard capacity. Apart from the installation size, geothermal heat effects are also determined by the energy consumption behaviour of the building structure itself, and the circulation pump of an auxiliary installation is a factor that cannot be ignored. Table 9 shows the energy consumption and cost characteristics for the application of a new renewable energy facility for each of the three cases.

Table 9. Annual energy demand per unit area of cases.

Description		Case 1	Case 2	Case 3
100% application of standard capacity	Demand quantity reduction (%)	6.68	10.00	7.29
	Use cost reduction (%)	6.75	9.79	7.41
25% application of standard capacity	Demand quantity reduction (%)	3.35	1.56	2.80
	Use cost reduction (%)	3.38	1.53	2.85

When comparing primary energy consumption per unit area, which is the currently used criterion of energy efficiency rating for domestic building structures, a higher saving rate was found in Case 2, with 100% of the standard capacity, compared to Case 3, with 25% of the standard capacity. This is thought to be a result of the basic energy consumption of a building structure, i.e., the decrease in the window area rate of the external wall area resulted in a remarkable decrease in the required heating energy accompanied by the maximization of the effect of the geothermal heating facility and a greater decrease in the power consumption of the EHP system in accordance with reductions in the cooling and heating energy of the geothermal system. Table 10 shows the annual primary energy consumption per unit area for each application of a new renewable energy facility.

Table 10. Annual primary energy demand per unit area of cases.

Description		Case 1	Case 2	Case 3
100% application of standard capacity	Demand quantity reduction (%)	7.77	13.20	7.64
25% application of standard capacity	Demand quantity reduction (%)	3.90	1.67	2.94

8. LCC Analysis by Geothermal Energy Facility

8.1. Repair and Replacement Cycle of the Applied Geothermal Energy Facility

In the LCC analysis conducted in this study, geothermal energy repair and replacement were based on an assumption of 40 durable years. To obtain more diverse results depending on the analysis period, the analysis was performed using a 10-year cycle. For items included in the specification, the rate and level of repair and repair and replacement cycles were applied, but when the items were not included in the specification, the durable years of items similarly categorized were applied. The LCC analysis used in this study was not for the entire building structure, but for the geothermal energy facility, and only the components of these facilities were analysed.

When calculating maintenance cost in terms of the repair cycle of the geothermal energy facility by primary process, the rate of repair level and the replacement rate of the geothermal heat pump were 10% at five years and 100% at 10 years. However, a replacement rate of 100% at 11 years was obtained for the expansion tank. When a new renewable energy facility is installed, a structure should be fitted to provide support for the fixation of a buttress and pump. A number of general processes usually applied to general facility work were also included, and the replacement rate of items was likewise analysed. The rate of repair level of the equipment of major components was identical to that of equipment and materials for general equipment work in which a heat pump was used, and there are many components with a short repair cycle; the repair cost was therefore shown to be high.

8.2. LCC Estimation of a Geothermal Energy Facility

LCC was calculated using the present value method. In the case of geothermal energy facility equipment for items that only have a replacement cycle, this was converted to nonrecurring cost for every repair cycle, while for items that have periodic repair and replacement cycles, this was converted to nonrecurring cost every repair cycle. Subsequently, all converted values and nonrecurring costs were summed to estimate maintenance cost. The discount rate applied to the estimation of maintenance cost was calculated using a real discount rate of 1.02%, obtained from the inflation and nominal discount rates based on the deposit interest rate for seven years.

The rate of increase of the average electricity fee between 2006 and 2012 was used to establish the inflation rate by referring to Monthly Energy Statistics issued in May, 2013; the value of 1.06% was used as the real discount rate obtained from the calculation of the rate of increase of a nominal discount to estimate energy savings cost. The initial investment cost was estimated by adding the costs of the applied geothermal energy facility calculation specification to variations in the amount accompanied by the replacement and dismantlement of the conventional facility. The construction cost of the wiring system installation for power was excluded, because it is not included in geothermal energy facility construction.

8.2.1. Calculation of Initial Investment Cost of a Geothermal Energy Facility

To calculate the initial investment cost of a geothermal system, the installed capacity of the existing facility should be changed. In Case 1, when 100% of the standard capacity was applied, a 116 kW outdoor equipment item was removed from the conventional EHP cooling and heating facilities and a new 23 kW outdoor equipment item was installed to preserve capacity. An indoor facility using the geothermal refrigerant method is compatible with the item of EHP outdoor equipment, and there was no influence on the construction cost of indoor facilities. The cost of the 116 kW outdoor equipment item was subtracted, and the cost of the 23 kW outdoor equipment item was added. When 25% of the standard capacity was applied, 75 kW outdoor equipment was removed and replaced with 52.2 kW outdoor equipment. In Case 2, when 100% of the standard capacity was applied, 52.2 kW, 71.8 kW and 78.4 kW EHPs were replaced, leading to a reduction in the initial investment cost. When 25% of the standard capacity was applied, with the substitution effect of a 52.2 kW EHP, the initial investment cost decreased. In Case 3, seven items of 46.4 kW EHP outdoor equipment and four items of 58 kW equipment, together with an item of 75.4 kW equipment were affected by the change. The construction costs of geothermal facilities have risen since the public announcement of the establishment of a base price in 2013. The design cost was calculated based on actual design drawings. In geothermal energy facility construction work, the drilling and installation costs of a geothermal exchanger were shown to be higher than the installation cost of geothermal equipment, along with the installation of a heat pump.

The capacity of the geothermal energy facility can be adjusted to be equivalent to the conventional cooling and heating facility; EHP equipment and installation costs that can be adjusted by case according to the application capacity were included in the initial investment cost of the geothermal system, but their value-added tax was not. The initial investment costs calculated with the construction cost for each geothermal energy type, as calculated based on the design drawings and adjustments in the capacity of the conventional load facilities, are provided in Table 11.

Table 11. Initial investment of geothermal energy facilities of cases.

Cases	100% application of standard capacity	25% application of standard capacity
Case 1	177,413,214	57,481,291
Case 2	282,115,135	87,934,371
Case 3	684,896,176	206,499,483

8.2.2. Calculation of Maintenance Cost of a Geothermal Energy Facility

The maintenance cost was obtained by adding replacement cost to repair cost. For items that only have a replacement cycle, this was converted to a nonrecurring cost for every replacement cycle, while for items that have periodic repair and replacement cycles, this was converted to a nonrecurring cost for every repair cycle. All costs were then added to the nonrecurring cost of the replacement cycle to estimate maintenance cost by analysis period. The maintenance cost of the geothermal system was determined to be higher when 100% of the standard capacity was applied. In the analysis of maintenance cost, it was found that with the exception of drilling work, most of the geothermal facility construction work in the three cases was similar to general cooling and heating construction work where a heat pump is applied; however, the maintenance cost was calculated as high due to a rise in repair and replacement costs resulting from the five-year repair cycle and from a 10-year replacement cycle for the heat pump.

8.2.3. LCC Calculation of a Geothermal Energy Facility

Based on the analysis of the initial investment and the maintenance costs of the geothermal energy facility in each case, the LCC was calculated for every 10-year analysis period. When 100% of the standard capacity was applied in all cases, the LCC of the geothermal energy facility increased as the analysis period increased. The LCC of the geothermal energy facility by analysis period for each case is shown in Table 12.

Table 12. The initial investment of geothermal energy facilities of cases.

Case	Analysis year	Application (%)	Initial investment	Maintain cost	LCC
Case 1	10	100	177,413,214	45,082,942	222,495,156
		25	57,481,291	22,929,864	80,411,155
	20	100	177,413,214	114,814,736	292,227,950
		25	57,481,291	52,607,724	110,089,015
	30	100	177,413,214	170,715,471	348,128,685
		25	57,481,291	78,901,211	136,382,502
	40	100	177,413,214	182,417,96	359,831,181
		25	57,481,291	86,793,300	144,274,591
Case 2	10	100	282,115,135	78,591,384	360,706,519
		25	87,934,371	29,083,243	89,533,243
	20	100	282,115,135	201,614,252	483,729,387
		25	87,934,371	70,780,448	158,714,819
	30	100	282,115,135	303,539,695	585,654,830
		25	87,934,371	106,299,141	194,233,512
	40	100	282,115,135	321,713,745	603,828,880
		25	87,934,371	114,652,882	202,587,253
Case 3	10	100	684,896,176	176,172,862	861,069,038
		25	206,499,483	64,219,177	270,718,660
	20	100	684,896,176	447,156,081	1,132,052,257
		25	206,499,957	157,211,330	363,710,813
	30	100	684,896,176	708,458,855	1,393,355,031
		25	206,499,483	236,056,719	442,556,202
	40	100	684,896,176	743,348,843	1,428,245,019
		25	206,499,483	248,408,375	454,907,858

8.2.4. A Comparative Analysis of the LCC of a Geothermal Energy Facility

In terms of geothermal energy, the cost savings effect did not appear to be in proportion to the application capacity, but differed in each case. Table 13 specifies the energy savings cost that accompanied the application of a geothermal energy facility in each case. The analysis showed that it is difficult to expect economic benefits from the application of a geothermal energy facility. Even though with the geothermal system the initial investment cost can be compensated for by adjusting the energy load capacity for the facility, this was not economically feasible, because of high initial investment and maintenance costs and low energy savings costs. This implies that the circulation pump required to operate the geothermal system consumes significant electricity, thus minimizing the energy-saving effect. Its initial investment cost is also high. To improve the economic feasibility of the geothermal energy system, less power-intensive circulation pumps and devices should therefore be selected and the initial investment cost should be reduced.

Table 13. Energy savings cost by applying the geothermal energy facilities of cases.

Case	Analysis year	100%	25%
Case 1	10	9,750,941	4,881,961
	20	18,526,071	9,275,367
	30	26,423,043	13,229,110
	40	33,529,739	16,787,188
Case 2	10	24,975,493	3,905,093
	20	47,451,603	7,419,390
	30	67,678,450	10,581,999
	40	85,881,127	13,428,114
Case 3	10	56,942,694	20,481,317
	20	108,186,936	38,912,998
	30	154,302,990	55,500,157
	40	195,804,051	70,427,381

It was not effective to estimate the period required to recoup the initial investment with the analysed data, since the difference between energy savings and initial investment costs was high. The return rate of LCC input through energy savings cost was thus used. In Case 1, the return rate of LCC for a new renewable energy facility increased as the analysis period increased, which indicates that the increase in energy savings cost was greater than that in the LCC of a geothermal facility. Thus, if the initial investment and maintenance costs of the geothermal energy facility are improved, the economic effect will be greater. The LCC analysis of the geothermal energy facility applied to each case is provided in Table 14.

Table 14. Accumulated operation and maintenance cost ($LCCO_2$ cost excluded).

Case	Analysis year	Description	100%	25%
Case 1	10	LCC	222,496,156	80,411,155
		Energy savings cost	9,750,941	4,881,961
		LCC collection ratio	4.38%	6.07%
	20	LCC	292,227,950	110,089,015
		Energy savings cost	18,526,071	9,275,367
		LCC collection ratio	6.36%	8.43%
	30	LCC	348,128,685	136,382,502
		Energy savings cost	26,423,043	13,229,110
		LCC collection ratio	7.59%	9.70%
	40	LCC	359,831,181	144,274,591
		Energy savings cost	33,529,739	16,787,188
		LCC collection ratio	9.32%	11.64%

Table 14. *Cont.*

Case	Analysis year	Description	100%	25%
Case 2	10	LCC	360,706,519	428,982,726
		Energy savings cost	24,975,493	3,905,093
		LCC collection ratio	6.92%	3.32%
	20	LCC	483,729,387	158,714,819
		Energy savings cost	47,451,603	7,419,390
		LCC collection ratio	9.81%	4.67%
	30	LCC	585,654,830	194,233,512
		Energy savings cost	67,678,450	10,581,999
		LCC collection ratio	11.56%	5.45%
	40	LCC	603,828,880	202,587,253
		Energy savings cost	85,881,127	13,428,114
		LCC collection ratio	14.22%	6.63%
Case 3	10	LCC	861,069,038	270,718,660
		Energy savings cost	56,942,694	20,481,317
		LCC collection ratio	6.61%	7.57%
	20	LCC	1,132,052,257	363,710,813
		Energy savings cost	56,942,694	20,481,317
		LCC collection ratio	6.61%	7.57%
	30	LCC	1,393,355,031	442,556,202
		Energy savings cost	154,302,990	55,500,157
		LCC collection ratio	11.07%	12.54%
	40	LCC	1,428,245,019	454,907,858
		Energy savings cost	195,804,051	70,427,381
		LCC collection ratio	13.71%	15.48%

9. Conclusions

This study aimed to analyse energy consumption in the application of new renewable energy systems to a public office building based on compulsory application criteria. The study also sought to determine an effective plan for the selection of a new renewable energy facility that takes economic feasibility into account by performing a comparative analysis of LCCs of new renewable energy facilities and energy savings costs from their application. Two main research findings were obtained. First, energy consumption and costs related to the application of a geothermal energy facility were analysed in three cases, to arrive at effective data for the selection of geothermal energy facility types. Second, the energy cost reduction effect relating to the application of a geothermal energy facility was examined, and an effective plan for the selection of a geothermal energy facility was presented by calculating the LCC using the initial investment and maintenance costs of a geothermal energy facility, the latter obtained by applying repair and replacement rates based on the construction specifications of each facility. It is believed that the results of this study can be utilized as an effective plan for the selection of a geothermal energy facility based on economic feasibility. In addition, the energy-saving effects on energy consumption and primary energy consumption will also be utilized as fundamental data in the understanding and selection of geothermal energy facilities.

However, the capacity of a new renewable energy facility was not simply calculated based on its energy production capacity; to analyse energy efficiency and economic feasibility in a more practical way, the energy production capacity and use efficiency of each new renewable energy facility should be utilized. The energy production capacity should be calculated based on the characteristics of each facility, and the energy-saving capacity resulting from the application should also be considered. Future work should analyse the energy use and cost characteristics of building constructions with new renewable energy facilities, and the results should be compared with the energy use characteristics of buildings, evaluated based on design drawings, to secure reliability. A study should also be conducted to prepare selection criteria for an appropriate facility by use, size and characteristics based on the actual performance of each new renewable energy facility.

Author Contributions

In this paper, Sangyong Kim developed the research ideas and organized research flow; Young Jun Jang implemented research program and collected data; Yoonseok Shin participated analysis of case study part; Gwang-Hee Kim completed the writing work of corresponding parts.

Conflicts of Interest

The authors declare no conflict of interest.

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