S12-3
ECONOMIC ASSESSMENT OF THE SOLAR-ENERGY SYSTEM USING LIFE CYCLE COST ANALYSIS

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ABSTRACT: As the use of new and renewable energy is one of the ways by which the exhaustion of fossil fuels and the other existing environmental problems can be addressed, a policy of spreading information regarding it and of conducting R&D related to it is currently being implemented in advanced countries. In the construction field, the concept of "green building" was born, and the application of this concept has increased, with the end in view of achieving energy savings, resource savings, and recycling, and of conserving the natural environment. In this context, the government of Korea amended the "Law on the Development, Use, and Promotion of New and Recycled Energy" in 2004, which contains 11 provisions related to new and renewable energy and their sources, including solar and geothermal energy as well as sunlight, water, rainfall, and organisms. Since solar-energy should be used instead of fossil fuels by converting sunlight directly into electricity, many researches on this subject are in progress. There are few researches, however, employing the economic approach to the subject. Thus, in this study, an economic assessment of the solar-energy system was conducted using both life cycle cost (LCC) analysis and sensitivity analysis. The results of the LCC analysis show that the solar-energy system will become economically better than the fossil fuel system after 16 years, although the initial construction cost of the solar-energy system is higher than that of the fossil fuel system. The results of this study are expected to be used in selecting an eco-friendly and economical solar-energy system when the construction of a green building is planned.

Keywords: Life cycle cost, solar energy, new and renewable energy

1. INTRODUCTION

1.1 Research Background and Purpose

The use of new and renewable energy (NRE) is one of the solutions to the problems of the exhaustion of fossil energy and environmental pollution. NRE research and development, and the policy of spreading information regarding NRE, are actively in progress in developed countries. In the construction industry, there have been attempts to use NRE based on the concepts of low- and zero-energy buildings. According to the "Law on the Development, Use, and Promotion of New and Recycled Energy," which was enforced in June 2004, over 5% of the total construction cost of new public buildings with a gross floor area of over 3000 m2 is mandated to be invested in NRE systems.

There were plans to expand this regulation, beginning this year, to construction projects involving the enlargement or reconstruction of a building. This law designated 11 energy sources, including solar energy, sunlight, water, geothermal energy, rainwater, and organisms, which are used as they convert the existing fossil fuels or renewable energy. In particular, solar energy converts sunlight directly to electrical energy. It is a welcome alternative to fossil fuels, and many researches on it are in progress.

Most of the studies on solar energy that are still in progress, however, aim to improve the efficiency of the system itself after presupposing the benefits of the solar-energy system. Some studies involve life cycle cost (LCC) analysis, but their sensitivity analysis for each variable is insufficient. Due to this, the aforementioned studies could not clearly provide LCC results to indicate how economically efficient the solar-energy system is and when the initial construction cost could be collected.

As such, this study was conducted to perform an economic assessment of solar-energy generation systems through LCC and sensitivity analyses, to select an eco-friendly and economical solar-energy generation system when planning the construction of a green building.

1.2 Research Methodology and Procedure

The literature review that was conducted in this study revealed that solar-energy systems are classified into and applied as passive systems, flat-plate types, vacuum-tube systems, central-receiver systems (dish type and powertower type), and others, according to the temperature that they use. In this study, the subject was limited to the vacuum-tube system (a two-layered vacuum and U tube), which can be used for the air-conditioning and heating of buildings, and which is expected to become widely used in the construction area. Furthermore, in this study, the economic efficiency of a solar-energy system was reviewed with respect to its LCC. The study was performed according to the following procedure and methods:

(1) The basic composition of solar-energy systems was determined by finding out the current status of their application to domestic buildings through literature review, and the economic-efficiency review method was examined, as well as the factors that influence the efficiency of the system.
(2) Based on the results of the literature review, the survey of the current status of the application of solar-energy systems to domestic buildings, and the interviews with experts, the payment and income costs according to the installation of solar-energy systems were defined, as well as the factors for LCC analysis.
(3) Basic assumptions for LCC analysis were set based on the results of earlier studies and on the data from the Korea Statistical Office.
(4) Finally, case studies were conducted, using LCC analysis, for the economic assessment of the solar-energy systems and to review their appropriateness through sensitivity analysis.

2. PRELIMINARY STUDY

2.1 Solar Energy Systems

A solar-energy system is a system that converts radiant energy from the sun to thermal energy and uses it for air cooling and heating and for water heating in a building. A solar-energy system consists of a solar-energy collection part, a storage part, and a part that uses the stored heat. Solar energy is converted to utilizable energy through these three processes.

The study conducted by [2] classified and proposed solar-energy systems in greater detail, as follows.

The solar-energy collection part includes a heat collection device that collects the solar energy, the pump, the fan, and the collected heat exchanger, which moves the collected energy to the storage. This part uses the flat-plate solar-collector method and the vacuum-tube solar-collector method, which have different heat collection temperatures. The storage part has a heat storage device that plays the role of a buffer that minimizes the loss of energy between the time when heat is collected and the time when it is used. In the system that is used to heat the air or the water in a building, water is generally utilized as the storage medium. The use part is where the stored solar energy is actually utilized. It generally consists of a subsidiary boiler for the utilization of the energy when there is inadequate solar energy.

2.2 Consideration of Previous Studies

(1) Previous Studies on Solar Energy

The domestic studies on solar energy focus on improving the performance of each solar-energy system. Among these studies, those on the solar-energy system, the improvement of the performance of the heat collector, the efficient design of subsidiary heat resources, and the efficient design of a water-heating system, among others, were undertaken. Among such previous studies, that by [3] analyzed the dependence of an alternative system on auxiliary heat sources of the solar-energy systems, such as LNG, gasoline, and midnight electricity, by conducting three LCC analyses of them to assess the economic efficiency of the solar-energy hot-water supply system, as well as its problems and improvement measures. No concrete LCC analysis of solar-energy systems has yet been performed, however, and the database on solar-energy systems is also insufficient.

(2) Previous Studies used LCC Analysis

Domestic studies on LCC analysis are actively being conducted in various areas. In particular, with the legalization of value engineering (VE), it is now being utilized in researches. The study conducted by [1] considered all the cost factors that surface during the life cycle, and the study by [4] was unique because it considered all the quantitative and qualitative factors.

Besides these studies, several studies assessed the economic efficiency of solar-energy systems through LCC analysis. Studies on construction machine systems are particularly being actively undertaken because their maintenance and repair costs are much higher than the initial construction cost. This also shows that LCC analysis is becoming more reliable.

3. FACTORS FOR LCC ANALYSIS IN SOLAR ENERGY SYSTEMS

To efficiently calculate and analyze the LCC, the cost factors for the subject of the analysis must be defined. In general, the initial construction costs, financing costs, operating costs, maintenance and repair costs, alteration and replacement costs, assignable costs, associated costs, and salvage value are included in the LCC [5].

3.1 Development of the Cost Breakdown Structure (CBS)

As mentioned earlier, LCC consists of various factors, including the initial construction costs and the maintenance and repair costs. The optimal proposal was selected based on these. This study assesses, however, the economic efficiency of the proposal rather than comparing two alternatives. It determined the payment and income cost factors as the basic components and implemented the structure based on the determination. Moreover, the planning and design costs that were incurred before the implementation of the systems were excluded from the CBS.

Table 1. Cost Breakdown Structure

Level 1	Level 2	Level 3	Details
Payment costs	Initial construction costs	Construction costs	· Equipment costs of solar-energy systems · Labor costs and other expenses incurred during the construction of the systems
	Operations, maintenance & repair costs	Maintenance and repair costs	· Regular cleaning costs · Partial maintenance and repair costs
	Disposal costs	Disposal costs	· Labor costs and other expenses incurred when disposing of the systems
Income costs	Initial construction costs	Construction costs	· Boiler construction costs to produce the same amount of heat as that produced by the solar-energy systems
	Operations, maintenance & repair costs	Maintenance and repair costs	· Regular cleaning costs · Partial maintenance and repair costs
	Salvage value	Salvage value	· Benefits of the disposal of solar-energy systems
	Other costs	Energy generation	· Cost of using as much oil as the amount of heat generated from solar energy
		Sales price of carbon emission reduction credits	· Sales price of the amount of carbon emission reduction from the use of solar-energy systems

CBS is divided into the payment costs and the income costs. They consist of the initial construction costs, operating costs, maintenance and repair costs, disposal costs, and salvage value factors. The payment costs are the costs incurred by the construction of solar-energy systems. They include the equipment cost, labor cost, and repair or disposal cost. The acquisition costs are the costs of acquiring existing solar-energy systems, which thus no longer need to be constructed. The income costs include the saved maintenance and repair costs according to the reduction of the capacity of the boiler, and the salvage value produced after the removal of the systems. In this study, it was assumed that the removal costs within the payment costs are covered by the salvage costs within the income costs. As such, they were not considered.

Table 1 divides the solar-energy-system classification system into three phases so that LCC analysis could be performed by confirming the cost data for each factor.

3.1 Basic Assumptions

LCC analysis was considered by [5] an economical assessment method that considers all the important cost factors incurred during the economic life of the factors, areas, and systems and then determines them as costs found at the same point. Information such as the discount rate and the analysis rate are additionally required to convert the basic cost information to the costs at a certain point, for the LCC analysis. Furthermore, assumptions such as the energy cost increase rate were determined, aside from the two basic assumptions, to assess the economic efficiency of solar-energy systems.

(1) Discount Rate

LCC analysis requires the conversion of all the costs incurred during a certain period to the costs at the same point. Generally, the costs that will be incurred in the future are converted to their present values, and the discount rate is applied in this process. The discount rate is calculated based on the nominal interest rate and the inflation rate, and each value is assumed through various methods of anticipation. In this study, the anticipated value based on the actual performance data was applied.

The linear-regression equation, the multi-regression equation, the log system method, and the index system method of computing the regression were applied by [4], who then used the log system method for the model with the highest expected accuracy. Therefore, the log system method was applied in this study based on actual performance data over 12 years, under the basic assumption that the economic situation in the future would be stable, to calculate the discount rate.

The rate of inflation was computed using the consumer price increase index between 2001 and 2007 provided by the Korea Statistical Office. The application of the log system regression equation yielded a regression of $y = -0.0047\ ln(x) + 0.047$. Using this equation, the inflation rate 20 years from now was calculated, and the arithmetic mean (2.24%) of each value was set as the discount rate.

For the nominal interest rate, the corporate loan interest rate for the last eight years (84 months) was used, as provided by the Bank of Korea, and the expected interest rates were calculated. Using the calculated arithmetic mean of these expected interest rates 20 years from now, the nominal interest rate was calculated as 4.93%. The application of both calculated values to the following equation yielded a discount rate of 2.63%:

$$i = \frac{(1+i_n)}{(1+f)} - 1 \qquad \text{Eq. (1)}$$

Where, i : discount rate, i_n : nominal rate, and f : inflation.

(2) Analysis Period

The analysis period was assumed as the life cycle of the solar-energy systems. According to "Appendix 5 of the Enforcement Regulations of Corporate Law (August 16, 2006)," there are two types of structures, and their life cycles are 20 years (15-25 years) and 40 years (30-50 years), respectively. These standards were applied to the buildings' subsidiary systems. Moreover, according to the Durable-Years Index for Tangible Fixed Assets (Korea Appraisal Board, 2003), the life cycle of air-conditioning and heating systems was determined to be 10-20 years. Furthermore, the interviews with experts revealed that the appropriate life cycle of solar-energy systems is 20 years. Therefore, in this study, the analysis period was set as 20 years.

(3) Cost-of-Energy Increase Rate

Unless the solar-energy system is used, oil is generally used to heat buildings. The rate of increase of the price of oil was estimated through a regression analysis based on the oil price data for the last 12 years. Using this, the predicted oil price increase rate 20 years from now was calculated as 4.07%. Furthermore, the increase rate in the amount of electricity required to operate a solar-energy system, 5.78%, was applied by finding the arithmetic mean of the electricity cost increase rates from 1999 to 2008.

(3) Other Assumption

With respect to the construction of solar-energy systems, this study considered only the direct payment costs. Moreover, the calculation of the income cost of solar-energy systems yielded a result that is the same as the cost oil required for generating the same amount of heat. Finally, to assess the economic efficiency of the solar-energy systems, all these costs were calculated based on January 2008.

4. LCC ANALYSIS USING CASE STUDIES

In chapter 3, the cost factors were determined for the entire "solar-energy system," including the subsidiary heat sources. As the obtained data were limited to the data for the solar-energy systems themselves and excluded the subsidiary heat sources, the economic-efficiency analysis that was performed in this study was limited to that of the solar-energy systems. Moreover, the standard point was set as January 2008, and all the costs were converted to their present values for the LCC analysis. In addition, as this study aimed to review the economic efficiency of solar-energy systems, it did not consider government subsidies in the construction of the current systems.

4.1 Selection of Case Studies

To evaluate the economic efficiency of solar-energy systems, certain cases were selected, as shown in Table 2. The female dormitory of 00 University is a case in which the vacuum-tube system was designed to provide 60% of the total required heat using the solar-energy systems, while 40% of the total required heat was provided by subsidiary heat sources.

Table 2. Summary of the Subject Cases

Classification	Details
Project title	Female dormitory of 00 University
Site location	Wonjusi, Gangwondo, Korea
Design conditions	Expected number of people using the systems: 400
	Expected amount of use per day: 24,000 Kcal/day
	Solar energy dependence rate: 60%
Systems scale	Heat collection area: 300.08 ㎡ (CPC1800 88 module)
Water heating method	Solar energy (main heat source), vacuum hot water boiler (subsidiary heat source)

4.2 LCC Analysis

(1) Cost Data Collection

For the LCC analysis, the cost data were collected based on the cost factors shown in Table 1. The details are shown in Table 3.

Table 3. Cost Data and Assumptions

Cost Factors		Details
Payment costs	Initial construction costs	315,084,000 won
	Maintenance and repair costs	6,301,680 won/year
	Energy cost (electricity)	125,192 won/year
Income costs	Energy generation	25,949,487 won/year
	Carbon emission reduction credit	1,516,224 won/year
Assumptions	Nominal interest rate	4.93%
	Inflation rate	2.24%
	Electricity charge increase rate	5.78%
	Oil price increase rate	4.07%
	Discount rate	2.63%
	Analysis period	20 years

The initial construction costs were converted to the present value of the amount in the proposal submitted in May 2006 by a solar-energy-system manufacturing company. Due to the absence of actual performance data, the maintenance and repair cost that was applied was 2% of the initial construction costs, which was generally accepted through the interviews with experts in the solar-energy-system manufacturing companies and in the Solar Energy Association. The energy cost was about 1% of the generated amount.

The income cost through the generation of energy was the monetary value of the amount of oil required to generate the amount of heat needed for a year, using the solar-energy systems, in the oil boiler, according to Eq. (2). The carbon emission reduction credit was determined by calculating the carbon emission reduction amount through the oil conversion coefficient and the carbon emission reduction coefficient, and then applying the price of the internationally traded carbon emission reduction credit.

(2) Setting of Assumptions

The assumptions used in the LCC analysis were as follows: a 20-year analysis period, a 2.61% discount rate, a 5.78% electricity charge increase rate, and a 4.07% oil price increase rate, as presented in chapter 3.2.

(3) Break-Even Point and Economic-Efficiency Analysis

The results of the LCC analysis of the solar-energy systems based on the cost data and the assumptions as of January 2008 are shown in Fig. 1.

If solar-energy systems would be established and operated to this day, the point at which the break-even points of the paid costs and the acquisition costs would be the same would be in August 2024, 16 years later. After 16 years, continuous revenues would be produced, and revenues of about KRW 62,272,000 would be posted in 2027, the final year of the systems' durable years.

If the government subsidies (50% of the initial construction costs) would be included and considered, the results would be more favorable.

4.3 Sensitivity Analysis

LCC analysis was performed based on the assumptions regarding the discount rate, the electricity charge increase rate, and the revenues from the carbon emission reduction credits. The initial construction costs, however, as well as the maintenance and repair costs and the amount of energy generated, could change. Therefore, sensitivity analysis was performed in this study, through Monte Carlo simulation, to check the change in the analysis results.

The distribution shape and range of the changes in the variables set for the sensitivity analysis are shown in Table 4. It was mentioned by [4] and [6] that as the prices for the initial construction costs and the maintenance and repair costs are set by the purchase or contract of lease of the systems, they have the same distribution scheme as the construction business costs.

As such, this study assumed the distribution scheme of the initial construction costs and the maintenance and repair costs to be beta distribution, and set the scope of change as +/-10%. For the electrical-energy charge, considering that the suppliers are limited, the distribution scheme was assumed to be equalized distribution, with a +/-5% range of change. The amount of heat generated by solar energy was converted to the amount of oil needed to generate the same amount of heat.

Therefore, in this study, the distribution of the cost data was estimated using the oil price data for eight years from the Korea Energy Economics Institute, and this resulted in a Weibull distribution. As there were insufficient accumulated data on the carbon emission reduction credits, it was assumed in this study that the trade price would increase based on reality, and the scope of changes was set as -10% to +10%.

$$\frac{\text{Generated amount of energy(kcal)}}{\text{Boiler efficiency} \times \text{Generated amount of energy from oil(Kcal/l)}} \times \text{Oil price}(won/l) \qquad \text{Eq. 2}$$

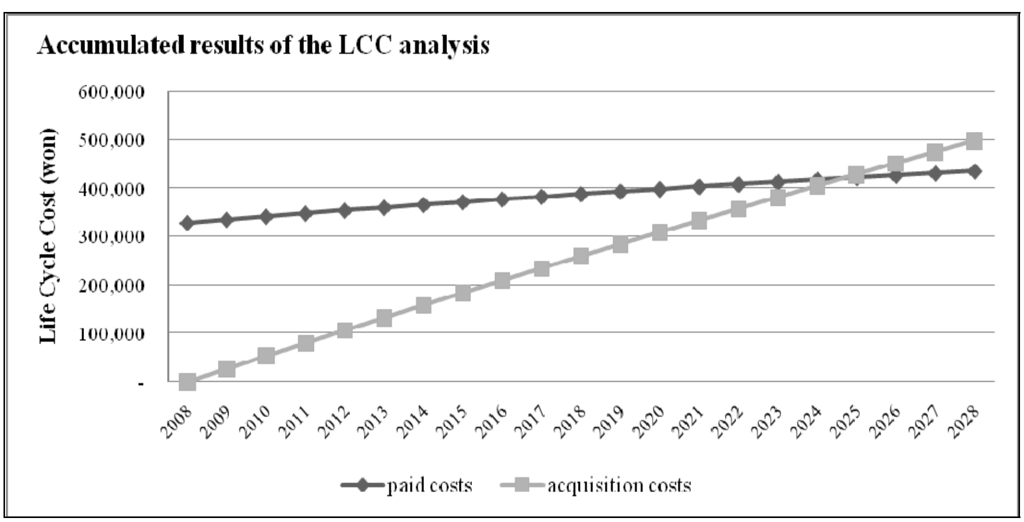

Figure 1. Accumulated results of the LCC analysis

Table 4. Distribution Schemes and Range of Changes by Sensitivity Analysis Variable

Classification		Distribution Scheme	Scope of Changes
Payment costs	Initial construction costs	Beta	-10% ~ +10%
	Maintenance and repair costs	Beta	-10% ~ +10%
	Energy cost (electricity)	Uniform	-5% ~ +5%
Income costs	Energy generation	Weibull	-30% ~ +10%
	Carbon emission reduction credit	Beta	-10% ~ +10%
Assump-tions	Nominal interest rate	Gamma	Scale: 10%
	Inflation	Gamma	Scale: 10%
	Electricity charge increase rate	Normal	Standard deviation: 3%
	Oil price increase rate	Normal	Standard deviation: 5%

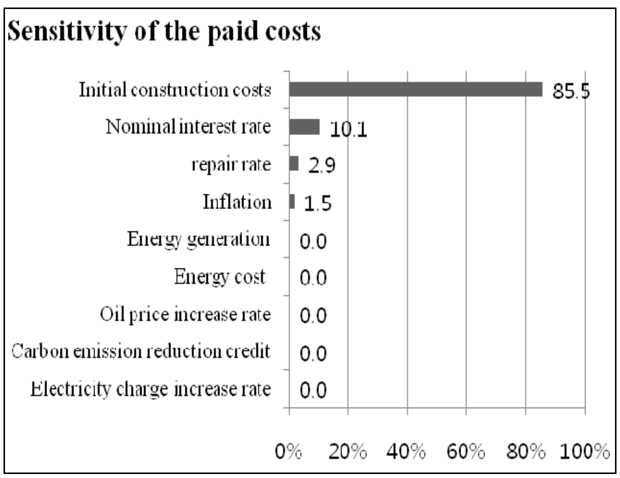

Figure 2. Sensitivity of the paid costs

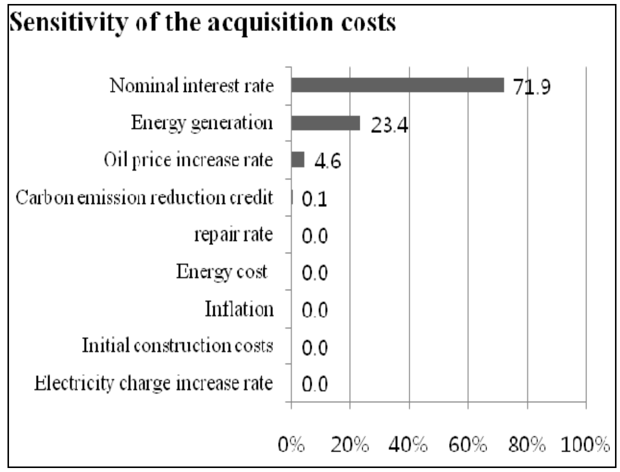

Figure 3. Sensitivity of the acquisition costs

The distribution schemes for the nominal interest rate, inflation rate, electricity charge increase rate, and oil price increase rate were set through the monthly change rate data from 2000 to 2007. As each factor was estimated based on the actual performance data, the width of the scope of changes was set to be comparatively small. For each variable, simulations were conducted for over 50,000 times.

The analysis showed that the range of changes in the paid cost was more narrowly distributed than that in the acquisition costs. It was thus deemed that the acquisition costs were relatively influenced more by the changes in the variables than the paid costs were. It was also found that the cost structure of the solar-energy systems could be reversed from positive to negative, according to the changes in the variables. If the government subsidies and the future improvement of the heat collector are effected, however, the economic efficiency will be sufficiently secured.

Fig. 2 and 3 show the sensitivity of the variables to the paid costs and the acquisition costs, respectively. The paid costs were most influenced by the initial construction costs, and the acquisition costs were most influenced by the nominal interest rates and the energy generation costs. The nominal interest rates were found to have a certain level of sensitivity to both factors, but it had an even greater influence on the acquisition costs.

5. CONCLUSIONS

As the interest in the environment grows, the efforts to reflect this interest in the construction area based on the concepts of low- and zero-energy buildings will also grow. Environmental concern in construction activities is materialized through the Law on the Development, Use, and Promotion of New and Recycled Energy. Thus, in this study, LCC and sensitivity analyses of solar-energy generation systems were conducted to assess their economic efficiency.

For such economic-efficiency analysis through LCC analysis, the paid cost factors (e.g., the initial construction costs and the maintenance and repair costs) were first determined based on the components of solar-energy systems. For the acquisition cost factors, the fuel savings and the revenue earned through the sale of carbon emission reduction credits were determined, and the discount rate or the analysis period was assumed. Moreover, LCC and economic-efficiency analyses were performed subject to the cases in which solar-energy systems were actually established, and the sensitivity analysis was performed using MCS to complement the uncertainty of the assumptions that were made.

The LCC and sensitivity analyses revealed that solar-energy generation systems become economically superior about 16 years after they are constructed. Due to the insufficient actual performance data, however, the predicted amount of heat to be obtained from the solar-energy systems was used in this study. Furthermore, the initial construction costs, repair rate, repair period, etc. were not applied according to the components of the systems. Instead, their integrated values were applied. Due to this, it would be slightly difficult to predict the revenue to be obtained from the construction of solar-energy systems.

Economic-efficiency analysis was conducted, however, through LCC analysis, based on the present data. Had the cost of each component factor, the repair rate, the repair period, the actual amount of heat generated by the systems, and the actual data, such as the sales prices of the carbon emission reduction credit, been additionally obtained, the results would have been more reliable. Furthermore, the results of this study are expected to help in the selection of environment-friendly and economical solar-energy generation systems when planning to build green buildings in the future.

ACKNOWLEDGEMENT

This work was supported by the Yonsei University Research Fund of 2009.

REFERENCES

[1] Kim, S., Cho, K., Kim, C., Hong, T., Hyun, C. and Koo, G., “A Study on the Life Cycle Cost Analysis for Waterproofing Work of Residential Building Basements”, Journal of Architectural Institute of Korea, 23(1), pp. 95-103, 2007.

[2] Baek, N., “Efficient Application and Design Technique of Solar Energy System”, Korea Green building Council, pp.94-140, 2005.

[3] Lee, B., “Verification Experiment and Analysis for 6kW Solar Water Heating System”, Air-conditioning and Refrigeration Engineering in Korea (SAREK), Vol. 17(3), pp.232-242, 2005.

[4] Lee, S., Woo, Y., Lee, S., Hong, T., Koo, K., and Hyun, C., “A Sludge Collector Selection Model by Life Cycle Cost Analysis, Journal of Korea Institute of Construction Engineering and Management (KICEM), Vol. 7(6), pp.175-184, 2006.

[5] Dell'Isolar, J. and Kirk, J., Life Cycle Costing for Systems, RSMeans, 2003.

[6] Spooner, “Probabilistic Estimating,” Journal of the Construction Division, 1974