A Case Study for Design Decisions on Building Service System using LCC Analysis

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Abstract

LCC (Life Cycle Cost) analysis is a practical method and a guideline for evaluating the economic performance of building service systems. By using the LCC analysis, the most cost-effective design decision can be made, which has the lowest LCC during the project study period among the various design alternatives. The present case shows an example of appropriate use of the LCC analysis, by demonstrating the procedures of decision-making among alternative building HVAC systems at Community Center and Congress Hall of a Local Government.

Keywords: Life cycle cost analysis; HVAC system, BLCC (Building life cycle cost), Sensitivity analysis, Cash flow diagram

1. Introduction

LCC (Life Cycle Cost) analysis, which considers the total expenses of facilities, including the initial investment costs, operation & maintenance expenses, and the final disposal costs, is a very practical method to use in deciding the investment budget with regards to energy saving for a building system in its design stage. It can evaluate the usefulness of building energy conservation and its economic value, and be used to select the most economical investment plan to building facilities. Therefore, this case study will endeavor to first come up with a plan to optimize the capacity of the building service systems, and then use it to show the decision-making process of selecting a more energy efficient and economical proposal (with the lowest LCC) for the HVAC system of Community Center and Congress Hall of a Local Government of district G.

The load calculation of plant equipment and HVAC system was abridged. The Trace 700 and System Analyzer were used to calculate the amount of the energy consumption, and BLCC (Ver.4.9) program was used for LCC analysis.

The object of the case study is to show the optimization processes for installation of building service system and prove its usefulness from the point of view of LCC analysis. Accordingly, optimization processes of building service system basically followed the protocols of the LCC analysis used in this study. Case studies of Community Center of Local Government were analyzed in order to conform to expenditures. The alternative proposal was selected in from the viewpoint of energy and cost savings. Since the total expenses calculation period for all the alternative proposals were the same, a general method for calculating current prices was used to generate the expenditure calculations. BLCC software was used to compute the LCC values for all the alternative proposals, and the proposal which had the lowest LCC was selected as the optimized proposal.

2. Protocols of LCC Analysis

The protocols of LCC Analysis are as follows;
(1) Basic research
Case studies of relevant objects and various financial figures are researched for the purpose of establishing an alternative proposal.
(2) Alternative proposal
The proposal must satisfy the minimum standard of performance, and should it go over the minimum standard, what added profit will result should also be considered.
(3) Making assumptions
Some variables like study period, discount rate, base date and so on are generally assumed for the LCC analysis. For example, the study period is generally set up to be within 25 years, with the life-cycle beginning from the service date.
(4) Itemized costs of the service system and the times of the cost generation
It consists of Initial Investment Costs, Operation, Maintenance & Repair Costs and so on. These costs are computed precisely at the times the costs are generated.
(5) Converting to present values of the expected itemized costs in future
Because the costs for analysis will occur at different points of time in the future, the future costs are converted to present values to make it possible to study them comparatively.

(6) Computing LCC for each proposal
The costs for each proposal should be gathered together for computing LCC.

\[
\text{LCC} = I + E + \text{OM \& R} + \text{Repl} + \text{Res}
\]

I : Present value of Initial Investment Costs  
E: Present value of Energy Costs  
OM \& R: Present value of Operation, Maintenance \& Repair Costs  
Repl: Present value of Replacement Costs  
Res : Present value of Residual Value

(7) Selection of Proposal with the lowest LCC
The proposal with the lowest LCC is selected from many alternative proposals. We calculate the difference between the Basecase and the Alternatives (LCC Basecase - LCC Alternative = Net Savings) and select the alternative with the biggest Net Savings.

(8) Non-quantifiable expenses and quality considerations of convenience
A factor such as convenience of users, while it cannot easily be quantifiable in terms of expenses, is nevertheless an important factor that indirectly affects the selection process of the alternative proposal.

(9) Sensitivity analysis
Many factors (discount rate for example) that influence the LCC analysis are assumed prices. Because their values can affect the outcome of the LCC analysis, wrong input data can produce wrong decisions. In order to prevent such problem from occurring, a sensitivity analysis is used to control the input data variables and how much influence the variables have over the LCC analysis is also researched.

(10) Computing the indexes to evaluate economical efficiency
The subsidiary indexes such as NS (Net Savings), SIR (Savings-to-Investment Ratio) and PB (Payback Period) can be computed if necessary to evaluate the economical efficiency of the proposal.

(11) Choosing the optimized proposal
After going through all the steps, the optimized alternative proposal is selected according to the results of LCC analysis.\(^3\)

3. Selecting the Alternative & Energy Consumption

3.1 Synopsis of the Building
Synopsis of the Building is shown in Fig. 1, Table 1, and Table 2.

3.2 Selecting the Alternative Proposal
According to the research on existing building service systems of three Community Centers for which data collecting was possible, the followings were found: for plant equipment, once-through boiler, smoke-tube boiler, vacuum hot water boiler, and absorption chiller are being used; for HVAC system, CAV+FCU are generally used, although in some buildings, PAC and heat exchanger are being used.

The energy consumption of three Community Centers are presented in Fig. 2 and Fig. 3. The usage of electricity is high in summer, and usage of natural gas is low in summer but high in winter. The highest energy consumption is recorded by Community Center C, which has gymnasia and a swimming pool. In addition, apart from the irregular gas consumption in winter, the annual gas consumption is lower than that of electricity.
There is a trend for community centers being built during these periods having complex functions including culture and sports facilities. It is considered that energy consumption level is going up rapidly at these centers, the plant equipment and HVAC system should be designed to minimize the cost for energy. The lower utility rate of midnight electricity could be used to reduce the energy cost. As Table 3 and 4 show, in choosing plant equipments and HVAC systems of building, the data from the three community centers could be refered. The existing plant equipment has been chosen as one proposal. The ice thermal storage system which uses midnight electricity rates and has high energy efficiency and the absorption chiller which uses natural gas were chosen as two alternative proposals.

Table 3. Alternatives for plant equipments

| Plant equipments | Basecase | ALT 1 | ALT 2 |
|------------------|----------|-------|-------|
| Ice thermal storage system 40% (1.617RT-H) | Ice thermal storage system 50% (1.971RT-H) | Ice thermal storage system 50% (1.971RT-H) | Ice thermal storage system 50% (1.971RT-H) |
| Screw type chiller (120RT=2 EA) | Screw type chiller (250RT=2 EA) | Screw type chiller (250RT=2 EA) | Screw type chiller (250RT=2 EA) |
| Steam boiler (1.5TON=2 EA) | Steam boiler (1TON=2 EA) | Steam boiler (1.5TON=2EA) | Steam boiler (0.6TON=1EA) |
| First, as a Basecase plant equipment, Ice thermal storage system 40%, plus Screw type chiller and Steam boiler were selected. Absorption chiller and Steam boiler was alternative 1 (ALT 1), and the Ice thermal storage system 50%, plus absorption chiller and Steam boiler were alternative 2 (ALT 2). From the LCC analysis of three plant equipment proposals, the optimized proposal could be obtained. That option was applied to two HVAC system proposals, and the final LCC analysis was proceeded.

Table 4. Alternatives for HVAC systems

| Floor | HVAC systems |
|-------|--------------|
| B1    | PAC          |
| B1    | CAV          |
| 1-4F  | FCU+CAV      |
| 1F    | FCU+CAV      |
| 1F    | PAC          |
| 2-4F  | CAV          |
| 5-6F  | FCU+VAV      |
| B1    | Heating +Ventilation |

3.3 Computing the amount of energy consumption

The energy consumption of alternative proposals was computed by Trace 700 and System Analyzer. The results are shown in Table 5, 6, 7, 8 and 9.

Table 5. Energy consumption of Base case (plants)

| Energy | Electricity | etc. | cooling source | Heating source | Cooling | Heating | etc. | TOTAL |
|--------|-------------|-----|----------------|----------------|---------|---------|-----|-------|
| unit   | kWh         | m³ | kWh           | kWh           | kWh     | kWh     | kWh | kWh   |
| Jan    | 0           | 7,575 | 3,107 | 7,046 | 31,494 | 42,176 |
| Feb    | 0           | 6,281 | 3,166 | 7,647 | 28,593 | 38,040 |
| Mar    | 0           | 7,413 | 1,583 | 3,062 | 31,028 | 40,024 |
| Apr    | 0           | 20,052 | 263 | 615 | 29,914 | 50,229 |
| May    | 0           | 38,901 | 0 | 0 | 30,865 | 69,766 |
| Jun    | 0           | 60,297 | 0 | 0 | 29,894 | 90,191 |
| Jul    | 0           | 73,838 | 0 | 0 | 30,890 | 104,728 |
| Aug    | 0           | 82,212 | 493 | 920 | 30,865 | 45,432 |
| Sep    | 0           | 65,315 | 0 | 0 | 29,914 | 95,229 |
| Oct    | 0           | 14,074 | 0 | 0 | 30,865 | 45,432 |
| Nov    | 0           | 11,166 | 1,478 | 2,722 | 30,021 | 42,665 |
| Dec    | 0           | 9,117 | 2,877 | 6,464 | 31,452 | 43,446 |
| Total  | 396,241 | 0 | 12,967 | 28,475 | 365,914 | 775,122 |

Table 6. Energy consumption of ALT 1 (plants)

| Energy | Electricity | etc. | Cooling source | Heating source | Cooling | Heating | etc. | TOTAL |
|--------|-------------|-----|----------------|----------------|---------|---------|-----|-------|
| unit   | kWh         | m³ | kWh           | kWh           | kWh     | kWh     | kWh | kWh   |
| Jan    | 10,173 | 0 | 749 | 3,107 | 7,516 | 31,494 | 44,774 |
| Feb    | 8,452 | 0 | 559 | 3,166 | 8,157 | 28,593 | 40,211 |
| Mar    | 9,391 | 0 | 751 | 1,583 | 3,266 | 31,028 | 42,002 |
| Apr    | 23,476 | 0 | 3,184 | 263 | 656 | 29,914 | 53,653 |
| May    | 33,650 | 0 | 9,420 | 0 | 0 | 30,865 | 64,515 |
| Jun    | 38,259 | 0 | 13,759 | 0 | 0 | 29,894 | 68,153 |
| Jul    | 39,511 | 0 | 18,915 | 0 | 0 | 30,890 | 70,401 |
| Aug    | 39,772 | 0 | 20,495 | 0 | 0 | 30,984 | 70,756 |
| Sep    | 34,868 | 0 | 11,313 | 0 | 0 | 29,914 | 64,782 |
| Oct    | 14,712 | 0 | 1,923 | 493 | 981 | 30,865 | 46,070 |
| Nov    | 11,269 | 0 | 950 | 1,478 | 2,903 | 30,021 | 42,768 |
| Dec    | 12,852 | 0 | 862 | 2,877 | 6,895 | 31,452 | 46,381 |
| Total  | 275,585 | 0 | 82,881 | 12,967 | 30,373 | 365,914 | 654,466 |
4. LCC analysis

4.1 Terms of analysis

- Period of building construction: from Apr., 2003 to Mar., 2004
- Service date: Aug., 2004

Period of analysis is set to begin with the service date of the building systems and lasts a term of 20 years. If the life spans of the alternative proposals are different, the proposal with the shorter life span becomes the standard, and the additional value of the proposal with the longer life span should be considered. The period of analysis was set using ALT 1, which has a life span of 10 years, and the period of analysis ended at the end of second ALT 1 life cycle in 2024. With ALT 2, which has a life span of 15 years, this would mean 5 years after the first replacement.

4.2 Major cost data

(1) Initial investment cost

Initial investment cost was computed using the figures at the date of analysis and corresponds to the estimated cost calculated at the job-site. TAB cost was excluded from the cost analysis. The computed result is presented in Table 10.

| Classification | Plant equipments | HVAC systems |
|----------------|-----------------|--------------|
| Planning cost  | Basecase 2,200  | Basecase ALT 1 |
| Construction cost | 2,200 | 2,200 |
| 471,900 274,670 | 568,320 | 899,057 955,914 |
| Support by KEPCO | -117,000 | |
| Deduction from tax | -48,330 | -29,938 |
| Total | 308,770 246,942 406,101,2 | 901,257 958,114 |
| Investment period | Planning/construction 2002.4-2004.3 |
| Service system installation 2003.4 – 2004.3 |
| Investment date year 2003 |

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(2) Regular operational cost

Operation, maintenance, repair, inspection, cleaning, labor and management costs were classified as regular operational cost, and their costs will vary greatly depending on the characteristics of building, system, and managing capabilities. Because of the difficulty in acquiring relevant data in Korea, the basic maintenance cost was estimated at 5% of the facility costs.

| Classification | Plant equipments | HVAC systems |
|----------------|-----------------|--------------|
| Wages 15,000 | 15,000 | 15,000 |
| OM & R 5,122 | 5,870 | 5,122 |
| 5,870 | 5,122 |
| Total | 20,122 20,870 19,935 | 20,122 20,870 |

(3) Irregular operational cost

Irregular operational cost differs from regular operational cost in that it is discharged not from profits.
that can be acquired or lost in building management but from the capital accounts. In this study, the irregular operational cost was set to zero; as it was assumed that there would be no sudden disorders during the whole operation period and total replacement after the life span. The replacement costs can be seen in Table 12.

Table 12. Capital replacement cost (unit: 1,000won)

| Classification | Plant equipments | HVAC systems |
|----------------|-----------------|--------------|
| Construction   | Base case ALT1  | ALT2 Base case ALT1 |
| Investment     | 2019. 8 2014. 8 | 2019. 8   |
| Expected life  | 15 yrs 10 yrs 15 yrs |            |

(4) Energy cost

In case of calculating energy cost, the electricity cost varies according to the purpose of building, contract with the power company, seasonal, weekly, or nightly operation times, total monthly electricity rate and so on. In case of natural gas (LNG) cost, the geographical location, purpose of building, and usage of gas (cooling/heating) are the variables to be considered. Table 13 shows the monthly energy rates. The water service cost was not considered in the calculations.

Table 13. Utility rates

| Classification | Calculated costs |
|----------------|------------------|
| Electricity    |                  |
| (public, option 1) | Demand contracted power charge (1,800kw) = 6,780(won/kw) |
|                 | contracted power(kw) |
|                 | × 6,210(won/kw) |
|                 | × night time consumption(kwh) |
|                 | × 26.2(won/kwh) |
|                 | + (daytime consumption(kwh) |
|                 | × 76.8(won/kwh)) |
| Electricity     | daytime consumption / total consumption(month) |
| (night)         |                  |
| LNG             | used for consumption(n2) × 195.26(won/n2) cooling (in Seoul) |
|                 | used for consumption(n2) × 499.84(won/n2) heating (in Seoul, commercial) |

(5) Remaining value of the facilities

Remaining value of the facilities at the end of the analysis period was calculated with a constantly decreasing rate of facility value going from 100% to 0% during life span of the facility.

Any additional significant cost data was calculated at present value of the analysis period. The real cost which will occur in the future will vary according to the inflation rate. The future cost is adjusted to present value with the discount rate taken into account when all the LCC alternative proposals are calculated and compared.

4.3 Consideration of cost variables

Consideration of cost variables is indispensable for LCC analysis. However, these have not been yet systematically collected in Korea and, in this study, the variables were calculated based on the data from the latest economic trends. Discount rate was acquired from the bank loan interest records since 1985, specifically concentrating on the changes since 1999, and the rate was set to 8% (Fig.4).

Price escalation rate was set based on consumer price index records since 1984. The price index for agricultural products and petroleum show unusually great fluctuations and have been excluded from the calculations.

The rest of the price index show conservative fluctuations that generally follow the ups and downs of economic trends, and with standard deviation of 2.5 to 5%, the rate of price index has been set to 5% yearly increase (Fig.5).

Yearly energy price escalation rate of gas was set to 0.1%, and that of electricity to 0.4%. These rates were set based on the energy price escalation rates since 1991 (Fig.6).
5. LCC analysis results

Ice thermal storage system 40% + Screw type chiller + Steam boiler was set as the Basecase primary equipment. In comparison, the alternative proposal ALT 1 uses Absorption chiller + Steam boiler, and ALT 2 uses Ice thermal storage system 50% + Absorption chiller + Steam boiler. The LCC analysis was applied on these three proposals to find the optimal primary system, and then that primary equipment was used to select two HVAC system proposals, on which the final LCC analysis was applied.

5.1 LCC analysis results of plant equipment

(1) Minimal LCC value
As shown in Figure 7, the cost of initial investment is minimal for ALT 1, but because of its large electricity consumption rate, the total LCC for ALT 1 is high. The Basecase and ALT 2 show low electricity consumption rate because they use overnight electricity. ALT 2 has the lowest energy cost, but the minimal total LCC value belongs to Basecase, which shows good sense of balance in its initial investment, energy cost, and operation, maintenance and repair cost.

(2) Sensitivity analysis on the LCC analysis results
Many of the LCC analysis indices are not exact, but assumed values, such as the discount rate variable. If the input values are incorrectly estimated, they could cause the analysis to generate the wrong conclusion. In order to prevent such a problem, the sensitivity analysis has been conducted to control the range of input variables and study the extent of their influence on the output values, thus safeguarding the integrity of the analysis results.

In this study, price escalation rate, discount rate, energy price escalation rate, energy usage and initial investment costs were each analyzed with a reasonable range of values by sensitivity analysis, and their results are shown in Table 15.

Fig.6. Gas and electricity price escalation rate

![Fig.6. Gas and electricity price escalation rate](image)

Fig.7. Comparison of total LCC for plant equipments

![Fig.7. Comparison of total LCC for plant equipments](image)

Fig.8. Accumulation costs in present value for plant equipments

![Fig.8. Accumulation costs in present value for plant equipments](image)

Table 14. Total LCC for plant equipments (unit : 1,000won)

| Classification       | Basecase | ALT 1   | ALT 2   |
|----------------------|----------|---------|---------|
| Initial investment   | 291,854  | 233,414 | 383,853 |
| Energy costs         | 386,829  | 1,525,947 | 364,166 |
| OM & R               | 278,774  | 289,137 | 276,183 |
| Replacement costs    | 285,529  | 191,975 | 343,598 |
| Residual values      | 166,170  | 0       | 199,964 |
| Total LCC            | 1,076,815 | 2,240,472 | 1,167,835 |

(*Total cost swing upward rapidly at the point of capital replacement occurred.)

Fig.8. Accumulation costs in present value for plant equipments

![Fig.8. Accumulation costs in present value for plant equipments](image)

Table 15. Sensitivity analysis (plants)

| Classification                    | Total LCC for plant equipments | Basecase | ALT 1   | ALT 2   |
|-----------------------------------|--------------------------------|----------|---------|---------|
| Price escalation rate             | 5% →2.5%                       | ▼ 10.6%  | ▼ 6.1%  | ▼ 10.6% |
|                                    | 5% →7.5%                       | △ 13.4%  | △ 8.2%  | △ 13.2% |
| Discount rate                      | 8% →5%                         | △ 31.5%  | △ 38.9% | △ 29.2% |
|                                    | 8% →10%                        | ▼ 15.2%  | ▼ 18.0% | ▼ 14.3% |
| Energy price escalation rate      | 4% → 4% + 0.05% yearly         | △ 1.1%   | △ 2.5%  | △ 1.0%  |
| Energy usage                      | + 10%                          | △ 3.4%   | △ 3.7%  | △ 3.1%  |
|                                   | − 10%                          | ▼ 3.4%   | ▼ 3.7%  | ▼ 3.1%  |
| Initial investment costs          | + 10%                          | △ 2.7%   | △ 1.0%  | △ 3.3%  |
|                                   | − 10%                          | ▼ 2.7%   | ▼ 1.0%  | ▼ 3.3%  |
In case of energy price escalation rate, as the rate increased, the energy expenses for all three proposals also increased, but did not affect their ranking.

Price escalation rate was added and subtracted by 2.5%, the value of which is standard deviation of price escalation rate from the 1980s. It caused the output of ALT 2 to change the most because it is influenced significantly by initial investment costs, maintenance costs, and replacement costs, etc., but Basecase still maintained its best expenditure ranking. With all the other variables tested with sensitivity analysis, the Basecase maintained its ranking with the lowest total LCC value.

The variable that most affected the final output was discount rate, in other words, bank loan interest rate. This means the rate is important in investment processes, not only directly affecting the costs, but also an important factor in indirectly affecting the alternative proposal selection as well.

As a result of analysis, the Basecase was selected as the optimal primary. The system was applied to two kinds of HVAC system proposals, and then a second round of LCC analysis was carried out to select the final optimal system.

5.2 LCC analysis results of HVAC systems
(1) Minimal LCC value
The analysis results of Basecase plant equipment applied to two HVAC system proposals are shown in Figure 9,10 and it can be seen that with respect to initial investment costs, energy costs and others, Basecase HVAC system is advantageous, and its differential value increases with the passage of time.

| Classification          | Basecase | ALT 1 |
|-------------------------|----------|-------|
| Initial investment costs| 851,883  | 905,625 |
| Energy costs            | 386,829  | 432,076 |
| OM & R                  | 830,590  | 869,98 |
| Replacement costs       | 544,110  | 578,353 |
| Residual values         | 316,657  | 336,585 |
| TOTAL LCC               | 2,296,763| 2,449,455 |

(2) Cash flow diagram
Cash flow diagram allows you to easily see estimated costs and times of expenditures. In the horizontal axis, estimated costs (future costs are calculated using current costs, price escalation rate, energy price escalation rate and so on) at the point of cost generation are indicated, and in the vertical axis, estimated costs at the point of base date are indicated. The total LCC for the whole period of analysis can be calculated as the sum of values at the vertical axis (Fig. 11, Fig. 12).

(3) Other economic indices
Net savings is defined as the total cost savings of Basecase expressed in currency value during the analysis period when compared with other alternatives, taking into consideration of all the factors such as the initial investment costs, operation, maintenance & repair costs and so on. Savings-to-Investment Ratio means the ratio of initial investment cost increase to the operation, maintenance & repair cost decrease. This ratio does not directly affect the selection of alternative proposals, but it does allow relative comparison of funds being employed by the Basecase and other alternatives.
In the LCC analysis, proposal with the smallest LCC is clearly the optimal one. However, cash flow diagram and other economic indices can be used to qualitatively check the propriety of the optimized proposal.

(4) Sensitivity analysis on the LCC analysis results
As it was done before, sensitivity analysis was applied again to price escalation rate, discount rate, energy price escalation rate, energy usage and initial investment costs within reasonable ranges of values. The total LCCs of the two HVAC system proposals fluctuated accordingly, but their fluctuation ranges were similar, and Basecase was still the most optimal in terms of total LCC value.

6. Conclusions
In this study, the LCC analysis was done to make the most economical proposal for the building service systems of the Community Center and Congress Hall in district G of a Local Government. Having applied LCC to three primary equipment proposals and two HVAC system proposals, it was found that Ice thermal storage system 40% + Screw type chiller + Steam boiler was the solution for optimal plant equipment, and CAV+FCU partially supplemented with VAV+FCU, PAC and so on was the solution for optimal HVAC system.

For a more reliable analysis, certain cost factors and price escalation variables should also be considered. Once actual systems operation data are compared, analyzed and put into a database, it can be predicted that LCC analysis in the design stage will become a more practical decision tool than it is now.

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