Life Cycle Cost Analysis of Air Conditioning Systems in a Perimeter Zone for a Variable Air Volume System in Office Buildings

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Abstract

In this paper, an economic analysis of systems adopted as the perimeter zone system in office buildings such as convector, fan coil unit (FCU) and fan powered unit (FPU) was performed, with the variable air volume (VAV) system applied in the interior zone. The initial cost of each alternative, such as the construction cost of the air conditioning system, was determined by planning and design, and energy cost as running cost was calculated on the basis of the energy consumption of each system using a computer simulation. Economic analysis was performed using life cycle cost (LCC), with the present value method for the air conditioning system in the perimeter zone. The results show that FPU is the most economical air conditioning system. When VAV is applied to the interior zone, LCC of the FCU is reduced by 6% and the cost of FPU is reduced 9% less than that of the convector system.

Keywords: perimeter air conditioning; variable air volume (VAV) system; convector; fan coil unit (FCU); fan powered unit (FPU); life cycle cost (LCC); LCC analysis

1. Introduction

Recently, the necessity of reducing energy consumption has become more important in Korea because of a rise in oil prices and a high dependence on foreign energy resources. In Korea, approximately 30% of the total energy is consumed in buildings, and approximately 50% of the building energy is consumed by air conditioning systems.

Therefore, methods for reducing the energy consumption of air conditioning systems in buildings are highly required.

Presently, the use of variable air volume (VAV) is increasing in an effort to reduce energy consumption. A VAV system in the interior zone of an office is mainly used for cooling. Unlike an interior zone where cooling is always needed, there is a heat load in winter for a perimeter zone. Thus, another method for managing the heating loads is needed in the perimeter zone. (Shepherd, K., 1999)

Heating methods in the perimeter zone are classified as air methods or water-air methods. The air method increases the supply air temperature by placing hot water or an electric coil in the perimeter terminal unit. Water-air methods, such as convector and fan coil unit, have a heating system that uses hot water. The FPU (Fan Powered Unit) as an air method, in which fans are added, is mainly used to prevent temperature stratification, which can occur through the supply of hotter air and a lesser amount of air. (Yang, I.H. et al., 2004)

Economic efficiency, which concerns comfort, initial cost, running cost and load management, should be considered in choosing perimeter zone heating methods. The design of the envelope and its relation to the heat sources should also be considered. Among these factors, initial cost and running cost such as energy consumption are related to economic efficiency, hence qualitative analysis is needed. Therefore, life cycle cost (LCC) analysis which includes both initial cost and running cost is becoming more important. In considering the LCC, the air conditioning system is the most important element.

The air conditioning system is the most costly aspect of the entire building's running cost. Therefore, minimizing the air conditioning system's cost should be a priority that is chosen through LCC analysis, considering basic cooling/heating functions and energy efficiency. (Yang, H.C. et al., 2002)

In this study, an economic comparison is performed using LCC analysis, including the initial cost and running cost such as energy consumption, when the VAV system is applied to the interior zone. Economic
Table 1. The Cost Items for LCC Analysis

<table>
<thead>
<tr>
<th>Phase</th>
<th>Cost items</th>
<th>Detailed cost items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Plan cost</td>
<td>Planning cost, Designing cost</td>
</tr>
<tr>
<td></td>
<td>Design cost</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>Construction cost</td>
<td>Material cost, Labor cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect cost</td>
</tr>
<tr>
<td></td>
<td>Aided cost</td>
<td>Financial aid, Tax aid</td>
</tr>
<tr>
<td>Running</td>
<td>Energy cost</td>
<td>Electric power cost, Gas cost</td>
</tr>
<tr>
<td></td>
<td>Water cost</td>
<td>City water cost, Sewage water cost, Water treatment cost</td>
</tr>
<tr>
<td></td>
<td>Running cost</td>
<td>Repair parts cost, Repair cost, Cleaning cost</td>
</tr>
<tr>
<td></td>
<td>General cost</td>
<td>Tax, Insurance, Labor cost of operation</td>
</tr>
<tr>
<td></td>
<td>Etc.</td>
<td>Interest of initial cost, Cost for space occupation, Aided cost</td>
</tr>
<tr>
<td>Disposal</td>
<td>Removal cost</td>
<td>Removal labor cost, Cost for waste treatment</td>
</tr>
<tr>
<td></td>
<td>Cost from sale</td>
<td>Profit from sale, Remaining value</td>
</tr>
</tbody>
</table>

Comparisons between each perimeter air conditioning method will be references in terms of the management of perimeter heating load.

For this, the economic efficiency of each of the following methods was estimated; VAV+convector, VAV+FCU and VAV+FPU in the office building. The heat source of FPU is hot water which is generally used in office buildings. In addition, CAV+FCU was compared with VAV+FCU, for the economic estimation in the interior zone. Furthermore, LCC analysis was performed, and only planning/design cost, initial cost and running cost were considered as items of cost. Disposal cost was not included in this study. The period of the LCC analysis was chosen to be 15 years.

2. The Selection of LCC Items

2.1 The selection of cost items

In terms of building construction, LCC analysis is performed most frequently for the optimal selection of building equipment systems. Running cost is mainly related to equipment systems such as air conditioning, sanitation and lighting. LCC items are selected to perform the LCC analysis of equipment including air conditioning systems.

In the planning and designing cost stage, as shown in Table 1., the schematic design cost is related to planning cost and the cost of design for construction is related to designing cost by considering the specific character of equipment design companies. Equipment design is mainly included in the engineering field. (Jung, J.R. et al., 2003) Therefore, the cost of planning and designing is determined according to the rate of the construction cost. However, if real design data can be applied, the data can be used for LCC calculation. In this study, planning/designing costs are calculated using the construction cost rating according to the Korean Engineering Cost Guideline standard. In calculating initial costs, including item prices and construction costs such as material costs and labor costs, it was determined to be below 200 thousand Won. Therefore, the planning and designing costs are determined by applying a rate of 2.42% in the schematic design and 4.85% in the construction design.

The cost of equipment and construction is calculated on the basis of the estimated amount that should be paid to the construction company by the owner, considering such costs as material, labor, and other indirect costs, which are calculated by the design of each air conditioning system alternative. In addition, air conditioning system alternatives are compared; therefore, the control system cost is included in the initial investment. While calculating, 2.26% of the total construction cost is applied to supervision costs, which is the same consideration as that for the planning and designing cost. Air conditioning equipment for the calculation of an estimated cost includes air conditioning duct and pipelines, diffusers, dampers, air handling units, etc. There were no differences between each method in terms of the equipment included, so plant systems were not considered. Aid from the government was divided into support from KEPCO(Korea Electric Power Corporation) or KOGAS(Korea Gas Corporation), encouragement for design, backup from the electricity fee policy, tax aid, and financial support. However, because these government supports are given equally to all companies, they were not considered. Electric power cost and fuel cost for main equipment and sub equipment were included in energy cost, and were calculated respectively. By using a computer simulation, the amount of energy consumption was calculated, subsequently, the total energy cost was calculated by applying to domestic electricity fees and gas fees. Electric power for ordinary use(The Gab) in the electric bill(January 1. 2008, KEPCO), and office heating/ordinary cooling in the gas bill(January 1. 2008, Seoul City Gas Co.) were applied to the calculation.

It is difficult to determine the running cost as sizes and kinds of air conditioning systems applied to buildings differ, and the management capacity is different in each building. Therefore, the application of a designer's technical experiences and decisions play an important role in the calculation of running costs. There are no domestic databases that have compiled these costs, as a result, there is insufficient basic data to use as a reference. The LCC analysis period was set to 15 years on the basis of the standards of equipment life. Therefore, the costs of repairing and replacing parts are not included.

Usually, general cost consists of tax, insurance, and the labor cost of operation. Tax is imposed on the building and sub equipments. Tax and insurance are not considered as they are equally applied to all these
alternatives, thus, only the labor cost of operation was included. This depends on the condition of labor, but other costs, including salary, were considered in calculating it.

In other costs, the interest on initial costs is generally calculated on the basis of a bank loan. The cost for space occupation results from the space gap of the machine room according to the differences in the air conditioning system. However all costs for space occupation and government-aided costs are equal according to the methods of the air conditioning system, therefore, those costs were not considered.

Removal cost occurs when the life of the air conditioning system exceeds that of the equipment and the system is removed. The remaining value in the sale cost is the wealth value at the end of analysis. These costs are applied equally to LCC calculations, therefore, they were not considered.

2.2 Selecting variables of cost items

The life of the equipment, interest rate (discount rate) and inflation were included as variables in the LCC analysis of the air conditioning system. The interest rate and inflation affect the value over time course. Especially, inflation is divided into increasing rates of prices, city water cost, sewage water cost, energy cost and insurance.

Generally, interest rate is used when the present value is converted to future value, and discount rate is used for the opposite case. The life of equipments means the period of LCC analysis. These variables mean the appropriate assumption values and mean values of former data are generally used as representatives and nominal rates for the estimation in LCC analysis. (Jung, S.S., 2004) In this study, the LCC analysis period was set as 15 years, which is the minimum life span of equipment in Korea, Japan, and the United States as shown in Table 2.

As the present value method was chosen in this study, the discount rate was applied to LCC analysis. The discount rate of air conditioning equipment is generally regarded to mean loan interest in the construction field. Thus, the interest rate of the next 15 years is calculated by the mean interest of the last 15 years. As Fig.1 shows, an analysis of the interest was conducted from 1992 to 2006, and the forecasted 15 years future interest rate for the next 15 years was calculated as 5.23%. Therefore, the discount rate for the next 15 years has been taken as 5% of the mean value.

In addition, as shown in Fig.2., the increasing rate of total prices has been determined to be the same as the discount rate. Thus, the increasing rate of equipment costs is applied as 2%. In the case of an increase in the price of electric power and gas, the mean value of the 15 years between 1993 and 2007 has been applied using an analysis of energy cost increases, as shown in Fig.3. and Fig.4. Thus, in this study, the increasing price rates are chosen as 3% for electric power and 6% for gas. In addition, as shown in Fig.5., the increasing rates of operation labor cost have been considered as 7% using the same calculation as that for energy costs.

2.3 Conversion method of LCC

Generally, all costs in the cost breakdown structure should be converted into the same time

![Fig.1. A Prediction of Discount Rate by an Average Interest Rate of Loan of the Construction Industry](image1)

![Fig.2. A Prediction of Increasing Rate of Total Prices](image2)

![Fig.3. Increasing Rate of Electric Power Prices](image3)

![Fig.4. Increasing Rate of Gas Prices](image4)
value to calculate LCC. There are three methods for the conversion of LCC according to the points of conversion; converting all costs into the present value(Present Worth Method), the annual value (Annual Worth Method), and future values (Future Worth Method). The present worth method and the annual worth method are most often used to calculate LCC. In this paper, the LCC analysis is performed using the present worth method which is mainly used for the comparison of the alternatives at the design stage.

Generated costs in the future are classified into recurring costs and nonrecurring costs. Recurring costs, including inflation, are converted into present values by Equation (1) and recurring costs excluding inflation are converted into present values by Equation (2).

where \( P \) is present worth, \( A \) is the regular amount payable at the end of a term for \( n \) years, \( i \) is the discount rates, \( e \) is inflation, and \( n \) is the analysis period. Nonrecurring cost generated in the future is converted into present value by Equation (3).

\[
P = A \times \frac{\left(\frac{1+e}{1+i}\right)^n - 1}{\left(\frac{1+e}{1+i}\right)-1}
\]

\[
P = A \times \frac{(1+i)^n-1}{i(1+i)^n}
\]

\[
P = F \times \frac{1}{(1+i)^n}
\]

where \( F \) is the amount payable at the end of \( n \) years. (Jung, J.R. et al., 2003)

### 3. Economic Analysis of each Air Conditioning System

#### 3.1 An outline of a model building and simulation

To perform the economic analysis of perimeter air conditioning in a VAV system, a model building was chosen. The building is used as office, and is located in the city of Incheon near Seoul. It is positioned toward the east, and the main entrance is located in the east. It has 18 levels above ground and 8 levels underground, and has a steel-framed reinforced concrete construction. Its air conditioning method is CAV+FCU, and it is controlled by a building automation system. An outline of the model building is shown in Table 3.

In this study, the initial costs are determined by adding or changing the values of the air conditioning methods, conditions of the air conditioning schedule, and design, based on the standards of this building’s plan. In addition, the amounts of energy consumption and running costs have been calculated using a computer simulation.

In this study, one level is chosen as a standard floor for the LCC analysis, and the area of the floor is 1047.38m², as shown in Fig.6. Area, size, location and size of core and size of glass windows are used as they exist. The values of air conditioning methods, conditions of the air conditioning schedule, and design have been added or changed to perform the simulation. The floor height of the building is 4m and the ceiling height is 2.7m. Furthermore, the depth of the perimeter zone is generally set to 3~6m, for this study, a value of 3m has been applied. The exterior walls of the building consist of gypsum board, rock wool and intermediate space, and the U-value was set to 0.4kcal/ m²·h·°C. Glass windows are instituted to colored multi-layer windows and the permeation rate of visible rays is 66%, reflectivity rate is 9%, and the shading coefficient is 0.6. In addition, the U-value of the glass was set up to 2.4kcal/ m²·h·°C. The total area of air conditioning is 814.03m² which comprises 523.03 m² for the interior zone and 291m² for the perimeter zone.

The building energy analysis program DOE-2.1E was used to calculate the initial costs and running cost. The heating and cooling loads of the building as well as energy consumption were calculated by simulation. With these values, the design of systems and plants was

<table>
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<tr>
<th>Table 3. Outline of a Model Building</th>
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<tr>
<td>Section</td>
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<tr>
<td>Location</td>
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<tr>
<td>Level</td>
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<tr>
<td>Structure</td>
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<td>Building area</td>
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<tr>
<td>Total floor area</td>
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<td>Air conditioning method</td>
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<td>Control method</td>
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</table>
performed to determine the running costs. Data fields for LOADS, SYSTEMS, PLANTS and ECONOMICS are input and the input file for DOE-2.1E is created based on the composition of the program. For the LOADS part, each material related to the location of the building and structure is input. In addition, the schedule of occupancy, lighting and infiltration was set up, and the design condition of the air conditioning and core is input. These input values are as shown in Table 4.

The space of the standard floor has been divided into 7 zones, 1 interior zone, 5 perimeter zones, and 1 core zone. Data in the LOADS part were input according to each zone. By using these data, the value of the heating and cooling loads can be acquired by simulation. In the SYSTEMS part, the on/off schedule of the air conditioning system and control condition of each zone were set up, matching each standard of the air conditioning methods. In addition, for the PLANTS part, the data of the boiler, chiller, and cooling tower were included. A steam type boiler, two-stage absorption chiller, and open type cooling tower were selected. Fig.7. and Fig.8. show the plan of systems which were applied in this paper.

### 3.2 Computation of energy consumption

Each input file for the air conditioning system alternatives was created and the amount of energy consumption was determined by simulation. In the case of the CAV+FCU method, total energy consumption was 169,965Mcal, which includes 29,609Mcal for electricity, and 9,935Mcal for gas. The VAV+convector method consumes a total energy of 169,196Mcal, including 24,204Mcal for electricity and 14,572Mcal for gas. And, for the VAV+FCU method, total energy consumption was 168,378Mcal, including 26,861Mcal for electricity and 11,097Mcal for gas. In addition, the VAV+FPU method consumes a total energy of 166,487Mcal, including 23,287Mcal for electricity, and 12,779Mcal for gas.

Comparison of energy consumption between each air conditioning method showed that when each method is applied separately to the interior zone, VAV can reduce total energy consumption by 10%, which is approximately 9.3% of the electricity and 10.5% of the gas when compared with CAV. FCU has been applied in the perimeter zone and both alternatives.

Furthermore, when VAV is selected in the interior zone, FCU can reduce approximately 2.1% of the total energy consumption of the convector method and FPU can reduce this by approximately 7.0%. The reduction rates of each air conditioning method are as shown in Figs.9. and Fig.10.

### 3.3 Calculation of Initial Costs and Running Costs

In this paper, when the VAV system is applied in the interior zone, each perimeter air conditioning method

![Fig.6. Plan of Standard Level of Model Building](image)

![Fig.7. System Plan of VAV+FCU or CON.](image)

![Fig.8. System Plan of VAV+FPU](image)

![Fig.9. A Comparison of Energy Consumption in Interior Zone Air Conditioning System](image)
is applied. With these applications, the initial costs and running costs are determined for the LCC analysis. A real estimate has been generated using each type of design to calculate initial costs. The total construction cost for each air conditioning method is lower than 200 million Won, hence, the rate of the supervision cost has been set to 2.26%. Therefore, the supervision cost is 2,566,348 Won for CAV+FCU, 3,036,056 Won for VAV+convector, 3,329,612 Won for VAV+FCU, and 3,610,775 Won for VAV+FPU.

In terms of initial costs, including those for construction cost and supervision cost, are shown in Fig. 11. In terms of initial costs, the VAV system is more expensive than the CAV system by 22.9%. In addition, the costs of FCU and FPU are greater than that of the convector method by 8.8% and 15.9%, respectively.

In terms of running costs, energy consumption has been determined using computer simulation. The running labor cost of CAV+FCU was 4,178,832 Won, VAV+convector was 4,943,667 Won, VAV+FCU was 5,421,669 Won, and VAV+FPU was 5,879,491 Won. Running costs, including running labor cost and the costs of electric power and gas, are shown in Fig. 12. VAV is lower than CAV by 15.6% in terms of running costs. In addition, FCU and FPU are both lower than the convector method by 11.0% and 18.3%, respectively, in terms of running costs.

4. LCC Analysis and Sensitivity Analysis
4.1 Analysis and evaluation of LCC
LCC analyses of each air conditioning method in the perimeter zone are shown in Table 5. The total LCC of CAV+FCU is 647,043,813 Won, VAV+convector is 645,636,805 Won, VAV+FCU is 607,335,840 Won, and VAV+FPU is 586,379,526 Won.

When the VAV system is selected in the interior zone, total LCC can be reduced by 6% in relation to CAV. In addition, by using the same condition, when FCU is chosen in the perimeter zone, total LCC can be reduced by 6% compared to the convector method. In the case of FPU with the same conditions, cost can be reduced by approximately 9% in relation to the convector method.

4.2 Sensitivity analysis
In LCC analysis, the items and variables of each cost were selected, and the method of converting LCC was determined. To select the cost item variables, a method of forecasting by analyzing the last 15 years data, including the analysis period, discount rate, increasing rates of energy cost, and labor cost was used. However, these variables greatly affect the forecast. In addition, the discount rate, which was calculated by considering changes in consumer prices and interest rates, was forecast. As a result, it was very difficult to obtain accurate values. By anticipating the changes in the LCC, more synthesized information can be given to aid in decision-making. Obviously, indexes of analysis have an important effect on the result, thus, it is necessary to use a sensitivity analysis to examine the effects on the conclusion according to changes in the variables.

In this study, sensitivity analysis was only performed in terms of applying the variables related to cost items. The extents of these values were changed to ±1% in each case, and economic analysis by sensitivity was performed.

The duration of sensitivity analysis was selected to be ±2 years, on the basis of 15 years. As a result, using the FPU method, total LCC was reduced by 8.4% for 13 years, 9% for 15 years, and 9.8% for 17 years. As shown in Fig. 13., if the analysis period increases, the investment effect also increases.

In the case of sensitivity analysis concerning the discount rate, the extent was set up to ±1%, based on 5%. So, in applying FPU, when the discount rates are
4%, 5%, and 6%, the total LCC is reduced by 9.6%, 9.0%, and 8.7%. The investment effect increases when the discount rate decreases, as shown in Fig. 14. Also, an analysis of the increasing rate of energy costs was performed. When the increasing rate of electric power cost was chosen to be 2%, 3%, and 4%, the total LCC was 8.7%, 9.0%, and 9.6%, respectively.

Furthermore, when the increasing rate of gas cost was set to 5%, 6%, and 7%, the total LCC decreased, going from 8.9%, to 9.0%, and finally to 9.5%, respectively. Thus, as shown in Figs. 15 and 16, the investment effect rises as the rate of energy cost increases. Moreover, when an increasing rate of labor cost was instituted at 6%, 7%, and 8%, the total LCC was 9.5%, 9.0%, and 8.9%, respectively. As the increasing rate of labor cost decreases, the investment effect grows as shown in Fig. 17.
5. Conclusion
In this paper, the economic analyses of systems adopted in the perimeter zone system in office buildings, such as convector, fan coil unit (FCU), and fan powered unit (FPU) were performed when the variable air volume (VAV) system was applied in the interior zone. For this, energy consumption was calculated by simulation. A model building and alternatives for air conditioning systems were selected. In addition, LCC cost items and variables were presented. Furthermore, total LCC was converted by the present value method and the results of this study may be summarized as follows.

(1) As a result of initial costs, in terms of the cost of materials and labor, FCU and FPU were higher than the convector system by 9% and 16%, respectively.

(2) Regarding energy consumption, FCU and FPU can reduce energy use more than the convector system, by 2% and 7%, respectively. Thus, FPU is the most effective system for the reduction of energy use.

(3) Concerning the result of total LCC cost, FCU and FPU can reduce the cost of the convector system by 6% and 9%, respectively. Thus, it is proven that when the VAV system is applied to the interior zone, FPU is the most economic system in the perimeter zone.

(4) Sensitivity analysis showed that the investment effect rises when the analysis period and increasing rate of energy costs go up. Furthermore, the effect increases when the discount rate and increasing rate of labor cost are reduced.

This paper focused on LCC analysis when a perimeter air conditioning method is designed. As a result, when VAV was selected for the interior zone, the FPU method in the perimeter zone was effective in both the reduction of energy use and economic factors. The best perimeter air conditioning method should be chosen, beyond economic considerations like LCC analysis, on the basis of building purpose and comfort such as indoor air quality. In addition, a model building was chosen to determine the costs in this study. Thus, for a more accurate result, specific studies need to be performed using data from real buildings with various conditions.

Acknowledgements
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References


