공동주택 단위세대의 생애 비용 최적화 방법론 연구

The Life Cycle Cost Optimization Methodology as a Tool for Designing Apartment Units.

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Abstract

The future costs of energy and the cost of the repair of apartment buildings are expected to rise continuously in proportion to the initial costs. Therefore it has become important for these increasing costs to be incorporated and reflected in the design of the building. Systems such as structure and services for the buildings remain constant, but a number of the walls and windows can vary and thus have a major influence on the total construction and running costs of a building. The critical factor in the apartment unit design for the optimization of life cycle cost (LCC) is the ratio of the x and y axis of the walls in the unit plan. This paper demonstrates how to achieve the optimal size and thus optimize the LCC of the building.

Keywords : Life-cycle cost, Apartment unit, Optimization methodology, Optimum size, Composite system

1. Introduction

Buildings are normally designed from the view point of the initial cost. However, more consideration should be given to the running cost of the building. This is because the running cost over the lifespan of the building is greater than the initial cost(Flanagan, 1983 ; Blanchard and Fabrycky, 1991 ; Dell' lsola and Kirk, 1995).

The running cost is usually in inverse proportion to the initial cost, so that the reduction of the initial cost affects the increase of the running cost. As a result, if a designer tries to reduce the intial cost, the running cost will increase. The opposite correlation is also true(Riverso, 1984 ; Dell' Isola and Kirk, 1995).

For this reason, it is necessary to design buildings from the perspective of the optimization of the life cycle cost.

In apartment buildings, because the wall and window systems of a unit are normally used repeatedly and the area of a unit plan and the number of the units on each floor are the same, the variation of the total length of wall and windows will influence the life cycle cost. Consequently, it is necessary to calculate an optimal shape between x and y axis of an apartment building' s unit plan for the minimization of the life cycle cost.

This paper focuses on the methodology used to calculate an optimum size of the apartment building' s unit plan in Korea.

2. LCC Categories for Appraisal and LCC Variations

2.1 Cost Categories for LCC Appraisal

As can be seen from Figure 1, the cost categories of the apartment building for the life cycle cost appraisal are broken down into planning and design cost, construction cost, operating and

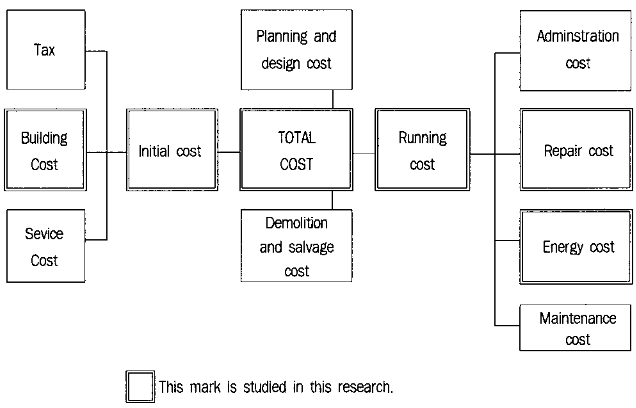

Figure 1. Cost categories for the life cycle cost appraisal.

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maintenance cost, and finally salvage and demolition cost, according to the project procedure. This research excludes the planning and design cost and the salvage and removal cost. On the one hand, the planning and design costs do not vary with the building system. On the other hand, the salvage-demolition cost has no meaning in Korea because estate prices are increasing very rapidly(Kim, 1982). Furthermore, the service charge and the cost of tax are not influenced by the composite system, for example, wall, floor, electrics, machine and so on, so that these costs are also excluded from this research(Park, 1992).

2.2 LCC Variations

LCC variations are related to the building systems of apartment buildings as shown in Table 1. The left column of the table represents the composite system, while the top row represents the costs category. The composite systems which are sensitive to LCC categories are marked with ○. It is the purpose of this research to examine these LCC categories.

Table 1. The correlations between composite systems with LCC categories

	Building cost	Mianten. cost	Admin. cost	Replace. repair cost	Energy cost
Base	○				
Floor	○			○	○
Wall	○			○	○
Electrics	○			○	○
Machine	○			○	○
Sanitary	○			○	○
Roof	○			○	○

3. LCC Factors and Net Present Value

Some variables which influence the building cost, the repair cost and the energy cost will be discussed in this chapter. These costs are very sensitive to the different types of composite systems.

This calculating methods of the building cost, repair cost and energy cost will be used for the case study (Chapter 5).

3.1 The Building Cost

The elements of the building cost include the material cost, the labor cost and the equipment cost. Moreover, these costs are influenced by a number of factors, such as the conditions in the supply systems of material and labor, the location of the building site for construction, as well as the inflation and the interest rates.

The variations of the building cost depend on the site location and are reflected by the location coefficient. The location coefficient represents the cost variation according to the distance from the datum area. If the location coefficient is 1 in the datum area, the other regions can be greater or smaller than 1. This research assumes that the location coefficient of Seoul to be 1.

3.2 The Repair Cost

The repair cost is calculated based on the Korea Replacement and Repair Standard (Ministry of Construction, Republic of Korea, 1987). This standard explains the frequency and the quantity of the building materials needed for the replacement and repair activities.

This standard is established and proclaimed to calculate the cost of Korean government managed apartments. The yearly cost to repair the old buildings are averaged and calculated to be used as the standard for government apartment repairing computation. In this standard, most of the materials are linearly assumed instead of curve as seen on the pattern(Figure 2). The cost computation standard is marked by preconstruction cost proportion. For example the floor plank used for the floor is replaced every 25 years and every 7 years, 15% of total construction areas is to be repaired according to the regulations.

Therefore, for optional construction cost would be initial cost times construction rate plus discount rate. It is assumed that the quantity of the deterioration follows a normal distribution pattern at time T1. Furthermore, it is assumed that the deterioration time is the threshold to be distributed regularly(Flanagan, 1983 ; Blanchard and Fabrycky, 1991 ; Dell' Isola and Kirk, 1995).

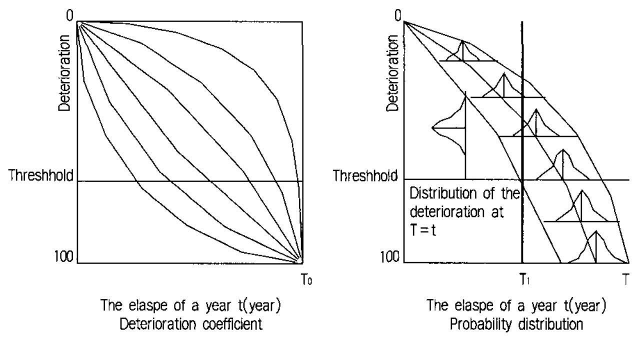


Figure 2. Deterioration coefficient and distribution

3.3 The Energy Cost

The energy usage of the building varies not only with the climate and life style, but also with the building shape, material, equipment system and operating pattern(Kim, 1989). But, the life style and the operating pattern are assumed to be constant in this paper.

Therefore, only the factors influenced by the composite system will be discussed in this paper.

The simulation of energy quantity was done using the statical method.

However this research will use the dynamic method for the energy simulation, which is DOE-2 computer simulation programme, using Korean climate data.

DOE-2 program is the computer program developed by the United States Departmet of Energy in order to analyze the Dynamic energy; energy consumption of buildings, energy amount change due to the climate. energy development due to the movement of the resident, are analyzed according to the time. This program can compute exact energy consumption by using the heat flow ratio of materials as the standard instead of using the statical energy analysing system. The basic presumption for energy consumption is as shown in Table 5.

3.4 The Net Present Value(NPV) Method

The total cost of the building is paid through out the life span of the building. All the costs must be summed up after calculating the time value, because these costs differ from year to year. For the calculation of the time value of the cost it is necessary to define a single point in time. This study uses the present value method, because the NPV is useful in comparing alternative designs with the same duration(Formula 1). It is assumed that all costs studied in this paper are paid at the end of each year.

$$C_p = \sum_{t=1}^{T} \frac{Ct}{(1+i)t} \qquad (1)$$

where, C_p : the net present value,

T : durable year of the building

C_t : cost at T years

i : real discount rate

$i = ((1+i')/(1+j)) - 1$

i' : interest rate at the market,

j : inflation

4. LCC Optimization Concept

The optimization of the unit plan is essential for minimizing the LCC. The LCC optimization of the unit plan of apartment building implies minimization of Formula 2.

$$LCC = \sum_{i=1}^{3}(\text{quantity of the composite system} \times \text{LCC unit price of the composite system}) \qquad (2)$$

where, i = the building cost, the energy cost, the repair cost

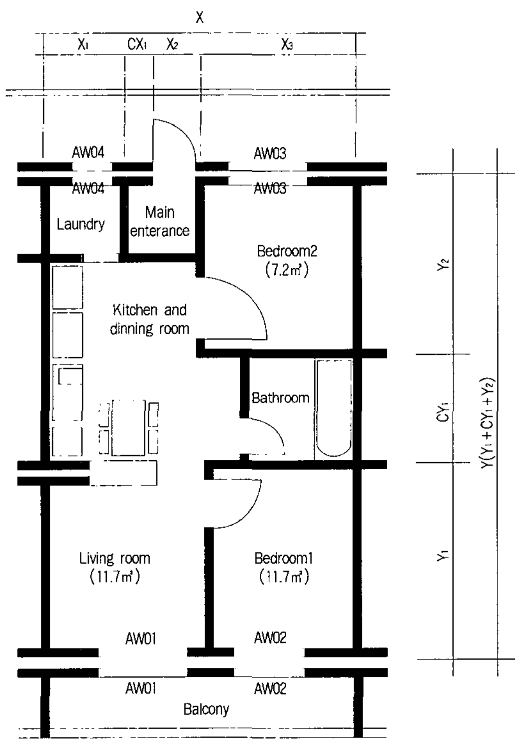
Assuming that the area of the unit plan is constant, if the dimension of the X axis becomes shorter, the dimension of the Y axis becomes longer. So, the LCC of the X and Y axis varies. Therefore, to calculate the minimum LCC of the unit plan, one needs to determine the x and y dimensions. Formula 3 expresses this concept.

$$\text{Min } LCC = \sum_{i=1}^{3}(\text{quantity of the composite system in the X axis} \times \text{LCC unit price of the composite system in the X axis}) + \sum_{i=1}^{3}(\text{quantity of the composite systems in the Y axis} \times \text{LCC unit price of the composite system in the Y axis}) \qquad (3)$$

where, i = the building cost, the energy cost, the repair cost

5. Case Study

Based on the concept of Chapter2, Chapter3 and Chapter4, an apartment building located in Seoul was chosen to be a case study. It has 14 floors although this may vary e.g thirteen or fifteen floors,



Hypothesis : Bath and Laundry room are constant.

Figure 3. Unit plan for the case study

Table 2. Building system and LCC of the composite system

Item	Symbol	System detail	LCC unit prices of system(won/m2)
Exterior walls	WE01 (Original)	Outside - 1. water paint 2 time 2. mortar 24mm 3. cement brick 90mm 4. insulation 50mm 5. cement brick 90mm 6. mortar 18mm Inside - 7. wall paper 0.5mm	268,196 (35,478)
	WE02 (Alt 1)	Outside - 1. water paint 2 time 2. mortar 24mm 3. cement brick 190mm 4. insulation 50mm 5. gypsum board 9mm Inside - 6. wall paper 0.5mm	255,553 (33,341)
	WE03 (Alt 2)	Outside - 1. red brick 90mm 2. insulation 50mm 3. cement brick 90mm 4. gypsum board 9mm Inside - 5. wall paper 0.5mm	227,446 (33,360)
	WE04 (Alt 3)	Outside - 1. water paint 2 time 2. concrete 150mm 3. insulation 50mm 4. gypsum board 9mm Inside - 5. wall paper 0.5mm	251,649 (29,461)
Walls between two units	WI01 (Original)	Inside - 1. wall paper 0.5mm 2. mortar 18mm 3. concrete 180mm 4. mortar 18mm Inside - 5. wall paper 0.5mm	39,268 (29,386)
	WI02 (Alt 1)	Inside - 1. wall paper 0.5mm 2. gypsum board 9mm 3. insulation 50mm 4. concrete 180mm 5. insulation 50mm 6. gypsum board 9mm Inside - 7. wall paper 0.5mm	45,574 (31,592)
	WI03 (Alt 2)	Inside - 1. wall paper 0.5mm 2. gypsum board 9mm 3. mortar 18mm 4. concrete 180mm 5. mortar 18mm 6. gypsum board 9mm Inside - 7. wall paper 0.5mm	48,719 (34,596)
	WI04 (Alt 3)	Inside - 1. tile 8mm 2. mortar 18mm 3. water proof liquid 4. concrete 180mm 5. water proof liquid 6. mortar 18mm Inside - 7. tile 8mm	309,644 (141,022)
Interior walls between two rooms	WI05 (Original)	Inside - 1. wall paper 0.5mm 2. mortar 18mm 3. cement brick 180mm 4. mortar 18mm Inside - 5. wall paper 0.5mm	37,090 (27,208)
	WI06 (Alt 1, 2, 3)	Inside - 1. wall paper 0.5mm 2. gypsum board 9mm 3. mortar 18mm 4. cement brick 180mm 5. mortar 18mm 6. gypsum board 9mm Inside - 7. wall paper 0.5mm	46,541 (32,418)

and one basement. The total number of units of that site is 1,330, and they are connected by one side corridor. This apartment building is supplied with a central heating system using oil. The area of the unit plan is 48.6 M2, as shown in Figure 3.

Table 2 and Table 3 present the details of the wall and windows systems used in the unit plan in Figure 3, and Table 4 shows four alternatives which is based on Table 2 and Table 3.

Table 3. Dimensions and details of windows

Item		Type	Size	System detail	Symbol	LCC unit price
Exterior Windows	Living room	WW01	1.8×2.0	• Storm window 1. outside 80mm aluminum window 3mm clear glass 2. Inside 36×60 wood frame 3mm semi-clear glass	OE02	• Case 1 = 107,663.46 • Case 2 = 109,582.19 • Case 3 = 111,078.89 • Case 4 = 112,636.58
		AW01	1.8×2.0			
	Bed room 1	WW02	1.5×1.2			
		AW02	1.5×1.2			
	Bed room 2	WW03	1.5×1.2			
		AW03	1.5×1.2			
	laundry	WW04	0.8×0.9			
		AW04	0.8×0.9			
Exterior doors	Ent-rance hall	SD01	0.8×2.0	• 1.0mm steel plate (both side filled rock wool) 40×100×1.6mm steal frame	OE02	• Case 1 =93,811.70 • Case 2 =94,552.83 • Case 3 =95,325.26 • Case 4 =95,741.31

5.1 Assumption for Energy Analysis

As shown in Table 5, the criterion of SBOC (Standard Building Operation Condition)[1], determined by DOE, has been adopted for the apartment building in order to analyze the energy of Figure 3.

The research relies on data of Seoul's Weather Data File which was established by Korea Institute of Construction Technology. This data is reformatted as the Design-Day format which is the same as DOE-2 Simulation Format. Only the amount of heating energy in Winter is calculated, because the apartment building in Korea does not operate a central cooling system in Summer.

The simulations lasted from the first of January to the 31st of March and from the first of October to the 31th of December. The weather data for these terms was calculated in average values. Then, Formula 4 was adopted to decide the boiler size using the heating energy load.

1) The way energy is used in buildings differ by the residents. United States Department of Energy takes all the movements and other energy developing factors that occur inside into the consideration as the standard to estimate the future energy consumption more efficiently.

Table 5. Assumptions for the energy simulation

Item	Assumption	Item	Assumption
Average heating degree	23℃	Number of the persons in the room	3 persons/unit
Electric energy for lighting	0.55KW/Hr	Electric energy for machinery and tools	0.5 KW/Hr
Generation of heat during cooking	1,200 Kcal/hr	Frequency of ventilations	0.6 time / Hr
floor weight	635 Kg/Hr	-	-

$$K = (Hr + Hg)(1 + \alpha)\beta / k \quad (4)$$

where, K : Regular heat generating capacity of boiler (Kcal/H)
Hr : Heating load (Kcal/H)
Hg : Load for hot-water supply (60Kcal/H)
α : Coefficient of heat loss for supply along with pipe line (hot water heating system, $\alpha = 0.35$)
β : Preheating load of boiler (It is $\beta = 1.65$)
k : Coefficient of capacity decrease (k =1)

5.2 Calculating the LCC Unit Price of the Composite System

The LCC unit price of composite system is the LCC per unit area of that system. In order to determine the LCC of unit plan, the LCC unit price which is the LCC of the composite system per area needs to be calculated. Table 6 is adopted to calculate the LCC unit price, while the results of Table 7 calculate the energy itself accordting to Figure 3. It is shown that the energy varies with the unit size (X, Y), and it determines the heat loads and the LCC unit price of the composite systems as detailed in Table 2. The heat loads are converted afterwards into the energy by using the Formula 4.

In the case of the energy calculation using the DOE-2 simulation programme, because the length of the wall, X, is variable, it is necessary to do regressions using Table 7 and to deduce the formula for calculating the energy load in Table 8. Furthermore, the formula of the building and the repair cost is deducted from the unit prices.

As shown in the result of Table 2, Table 3 and Table 8, it is

Table 6. Assumption for calculating the unit price of the composite system

LCC Factor	Assumption for calculating LCC	LCC Factor	Assumption for calculating LCC
Life span	30 year	Standard for replacement-repair	Replacement-repair Standard for Korean Apartment Houses
Interest rate	12.5 % /year	real discount rate	2 % /year
Inflation	10 % / year	-	-

* Calculating the real discount rate shown in Formula 1.

Table 7. The result of the energy analysis according to Figure 3

((-) MBTU/㎡)

Item	Size 1	Size 2	Size 3	Size 4	Size 5	Size 6	Size 7	Size 8
	5.1×9.5	5.5×8.5	5.7×8.5	6.0×8.1	6.1×8.0	6.4×7.6	6.8×7.1	7.3×6.7(m)
WE01	0.198799	0.228385	0.243812	0.258450	0.261234	0.273167	0.298068	0.309400
OE01	0.226867	0.246135	0.266217	0.277033	0.283100	0.356233	0.390650	0.452950
OE02	0.724597	0.774480	0.813391	0.853888	0.866321	0.893429	0.909896	1.095484

Table 8. The regression formulas of building systems based on Table 7.

Item	Original	Alt. 1	Alt. 2	Alt. 3
Exterior Walls	39369.4 X - 55880.9	39445.1 X - 56772.6	- 30787.8 Y 432434.4	40974.7 X - 58840.4
Windows	- 82.2 X 239824.3	- 74.7 Y 239994.2	- 67.3 Y 239899.4	- 82.4 Y 240072.2
Equipments	- 5455.4 X 447846.5	- 4964.6 X 447244.7	5313.9 X - 447554.9	- 5091.7 X 446888.7
Total	44742.6 X - 263903.0	44409.7 X - 74.7 Y - 105889.0	5313.9 X - 30855.0 Y 224773.8	46066.4 X - 82.4 Y - 265649.0

confirmed that the price of each unit usually varies according to the variations of the wall length and windows located at the exterior.

5.3 Calculation of the Optimum Size

In order to calculate the optimum size of the unit plan for the alternatives, Table 9 shows the formulas for building cost, repair cost, energy cost and LCC.

As a result, Table 10 which determines the optimal size, is deduced from Table 9. The optimum size of the original alternative is Y = 5.52m and X = 8.72m.

After deciding the optimum size, it is necessary to be examined if the optimum size satisfies the restrictive conditions of the rooms. If the size according to controlled size in Table 10 satisfies these conditions, the LCC minimum size will be the optimum size. If it

Table 9. Total cost of alternatives

Item		Details of Formula	Total
Original	EC	33975.2 X - 367886.9	647516.7 X
	BC	290596.8 X + 271394.7 Y - 2244131	+ 534086.8 Y
	RC	272944.7 X + 262692.1 Y - 2126795	- 4003039.1
Alt. 1	EC	34480.5 X - 74.7 Y - 528011.5	591365.7 X
	BC	279016.4 X + 285119.8 Y - 2212598	+ 555709.8 Y
	RC	277868.8 X + 262692.1 Y - 2150723	- 3835309.5
Alt. 2	EC	- 5313.9 X - 308011.5 Y + 1119954.3	464646.8 X
	BC	299902.2 X + 314751.7 Y - 2416388	+ 306986.9 Y
	RC	170058.5 X + 300246.7 Y - 1746240	- 3042673.7
Alt. 3	EC	35883 X - 82.4 Y + 628112.6	585855.4 X
	BC	279861.4 X + 298665.3 Y - 2289996	+ 583586.2 Y
	RC	270111.0 X + 285003.2 Y - 2204975	- 3866858.4

EC = energy cost, BC=Building cost, RC = repair cost

Table 10. The results of LCC minimum shape for alternatives

Item	Original	Alt. 1	Alt. 2	Alt. 3
Total area(㎡)	49.5	49.5	49.1	49.7
LCC minimum size(m)	6.4×7.75	6.8×7.26	5.7×8.61	7.04×7.06
Controlled size(m)	6.3×7.8	6.9×7.2	5.7×8.7	6.9×7.2
Bed room size(m) (proposed)	x1 = 3.3 y1 = 3.9 y2 = 2.1	x1 = 3.6 y1 = 3.3 y2 = 2.1	x1 = 3.0 y1 = 4.5 y2 = 2.1	x1 = 3.6 y1 = 3.3 y2 = 2.1
LCC(Dollar/㎡)	14,738.4	15,650.9	14,151.4	15,881.4
Building cost (Dollar/㎡)	3,574.1	3,809.0	3,830.5	3,845.2
LCC/Building cost	4.12	4.11	3.69	4.13

does not, the LCC minimum size will be adjusted to a proper size. The conditions for the optimum size are suggested as follows;

1) The dimensions of the laundry, bath, windows and doors are constant.

2) LCC minimum size, X, Y must satisfy next conditions.

(1) $X \geq 2.4$ (bathroom length) + 1.5 (laundry length) + 0.9 (door width) = 4.8 (m)

(2) $Y \geq 2.2$ (bed length in northern bedroom) + 1.8 (short length of both rooms) + 2.2 (bed length in southern bedroom) = 6.2 (m)

(Note : The precondition is to be set in the bedroom freely)

$\therefore$ 4.8 m $\leq X \leq$ 7.8 m, 6.2 m $\leq Y \leq$ 10.1 m

In Figure 4, all of the LCC minimum length for X and Y are expressed by the restriction conditions, 4.8m $\leq X \leq$ 7.8 m. So, all of the alternatives are satisfied with restrictive condition.

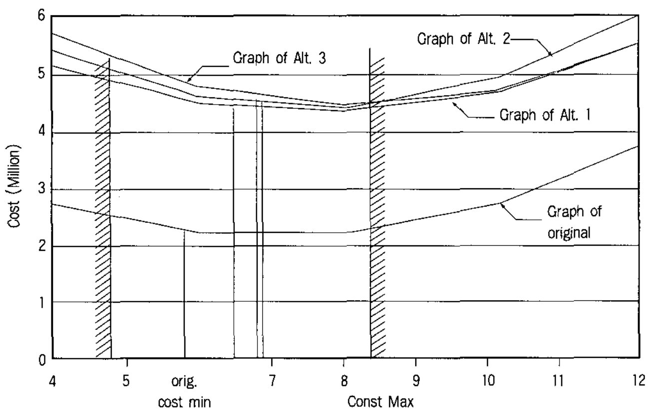


Figure 4. The restriction of the optimum size

The LCC minimum length of X is 6.4m, 6.8m, 5.7m and 7.04m, in Table 10. But the size can not be adapted to the design, because it is not suitable for the Korean modular system. In the case of the Korean modular system, units vary by 10cm or 30cm. So, the unit size of the LCC minimum shape needs to be controlled in order to fit with the Korean modular system. If one considers the values obtained for the controlled size, the nearest to the LCC minimum length X is 6.3m, 6.9m, 5.7m and 6.9m.

The LCC minimum alternative is Alt. 2. Its LCC and the Building cost is 14,151.4(Dollar/㎡) and 3830.5(Dollar/㎡), while a ratio of the LCC and the Building cost is 3.69.

If one compares the LCC of Alt. 2 with the LCC of Alt. 3, one notices a difference of 1730.0(Dollar/㎡) between them. It means that choosing Alt. 2 in the design stage can saves about 10.89% of the LCC when comparing with the Alt. 3.

6. Conclusions

The cost categories for the life cycle cost appraisal, influenced by the building system of apartment building, are the building cost, repair cost and energy cost.

These costs vary according to several factors. In the cases of the building cost, these factors are labor cost, material cost and equipment cost. For the repair cost the respective factors are the location of the composite system in the building. The energy cost vary with the weather, building systems and the energy consuming patterns.

The LCC minimum size that optimizes the life-cycle cost of the unit plan is determined based on the quantity of the composite system multiplied by the LCC unit price of the composite systems.

The optimum size has to respect the required living conditions and reflect the modular coordinations of given country.

In this research, Korea was chosen as the case study, however, energy consumption factors, repair cost computation standard, construction cost computations were to be applied for other countries, it will be a very useful case study of reduction of LCC of unit plan of apartments. Especially it is estimated that if the architect were to use this theory at the initial stage, the running cost could be cut by a quarter by escaping the initial construction cost oriented construction.

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요 약

최근 공동주택의 유지관리를 위한 인건비, 에너지비가 급속하게 증가하고 있다. 이에 따라 설계단계에서 이 비용을 절감할 수 있는 기법의 필요성이 제기되고 있다.공동주택에 있어서는 대부분의 경우 세대당 동일한 내외벽, 창호 등이 반복적으로 사용되므로 단위평면의 LCC 최적화가 전체 건물의 LCC 최적화에 있어서 가장 중요하다. 이를 위하여 본 연구에서는 LCC 비용항목 중 공동주택의 물리적 시스템에 탄력성있게 변화하는 LCC 비용항목을 파악하였고, 초기건축비, 보수교체비, 에너지비를 종합적으로 최적화시킬 수 있도록 LCC 부위단가 개념을 도입하여 공동주택 적정치수 산정방법을 제시하였다. 여기에서 보수교체비산정은 보수교체비용 최소화에 의한 최적 보수교체주기법에 근거하였으며, 에너지 소비량 추정은 DOE-2에 의한 동적 에너지 부하량을 추정하여 LCC 부위단가 개념에 접목하였다. 보수교체비 최적화 기법과 동적에너지 분석에 의한 LCC 부위단가 개념은 기존의 개념과는 다른 독창적인 개념이다.

키워드 : 생애비용, 공동주택 단위세대, 최적화 방법론