ECONOMIC ANALYSIS BY GLASS TYPES IN BALCONY CONVERSION OF MULTI-FAMILY HOUSING PROJECTS

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Abstract

Energy-saving is one of important issues in multi-family housing projects in South Korea. According to the study by Yu et al. (2002), the balcony conversion causes energy loss approximately one and a half times. Therefore, it is important to select the economical glass type in the balcony window. In order to identify the most economical glass type of balcony conversion in multi-family housing projects, the most typical type of the multi-family housing projects in the metropolitan area was selected as a candidate project. The selected candidate project has been simulated using ENERGY-10 program to estimate the heat load by the different five types of glasses as well as their life cycle cost analysis (LCCA) using present worth method. Finally, sensitivity analysis has been conducted to determine the most economical glass types under a different discount rate (interest rate) and service life of building.

Keywords: Economic analysis, Multi-family housing projects, Life cycle cost analysis, ENERGY-10

Symbols

TOE	10million ㎉
A	Air, ㎜
T	Thick, ㎜

1. Introduction

1.1 Background and Purpose

In an energy saving point of view, energy saving is a strongly important issue in multi-family housing projects in Seoul, South Korea since the multi-family housing projects account for approximately 50% of the residential housing in Seoul (Korea National Housing Corporation 2003). About 97% of the total amount energy consumption (160,451,000 TOE) has been imported from abroad. Under such a circumstance, approximately 21% (34,297,000 TOE) has been used at the building maintenance in South Korea in 2002. Therefore, the energy saving to multi-family housings is a nationwide concern (Korea Energy Management Corporation 2002).

The largest energy loss especially comes from the windows directly facing the air and in particular, the front balcony window, because it is relatively much larger than other windows in a multi-family housing. According to Yu et al. (2002), the energy loss can be increased approximately 1.5 ~ 1.6 times by the recent balcony conversion. Thus, it is important to select an economical glass type for the balcony window. In this paper, the most economical glass type for balcony conversion in multi-family housing projects is selected by using life cycle cost analysis.

1.2 Scope and Methodology

The Apartment-Application Deposit System (AADS) has been in effect since 1978. It has been enforced to more or less than nettable area of a total of 40 square meters in case of multi-family housing projects built by the public sector. In case of multi-family housing projects built by the private sector, it has been operated to more or less than nettable area of a total of 85 square meters. Since then, the typical size has been fixed to this size, which is defined as a regular size in the multi-family housing market.

Therefore, a multi-family housing unit less than the nettable area of a total of 85 square meters are selected as a case study in this research. The selected unit is comprised of 3BLDK (3 Beds + 1 Living room + 1 Dining room + 1 Kitchen) in the new town, Gangil-District, Seoul Korea, assumed that the balcony is converted.

ENERGY-10 (Version 1.5) is used to calculate the heat load quantitatively based on the glass type of the selected case study. Through the life cycle cost analysis (LCCA) including the initial cost and energy cost with regard to each balcony glass types, this paper suggests the most economical balcony glass type.

However, there are several uncertainties such as a discount rate, inflation, and service life in LCCA. Especially, the end of service life for reconstructing multi-family housing projects will be strengthened from 20 years to 30~40 years. In order to consider these uncertainties, the sensitivity analysis on the results of LCCA is performed under different discount rates and service lives of a multi-family housing projects.

2. Methodology of LCC Analysis

2.1 Selection of Glass Type

Table 1 shows the types of glass used for front and back balcony windows in this research. For economical comparison by glass type, this study focuses on the glass types specified in the Korea Design Standard for Building Energy Savings. Among these glass types, this research selected the clear double-paned glass, typically used in multi-family housing projects, and Low-E Glass, which has a good heat effect. Aluminum frames with a thermal break, generally used in multi-family housing projects, was also selected.

In the glass component “6+12A+6” of Table 1, the left 6 represents the outer pane thickness; the middle 12A the air thickness; and the right 6 the inner pane thickness.

Additionally, the symbol "|" represents the coating layer that is coated inside the double-paned glass and is illustrated in 'c' of Figure 1.

Table 1: Selection of Glass Type

Frame Type	Glass Type	Thickness	Component
Aluminum Frame + Thermal Break	Clear Double-Paned Glass	16T	5+6A+5
		18T	6+6A+6
		24T	6+12A+6
	Clear Low-E Double-Paned Glass	18T	6+6A+|6
		24T	6+12A+|6

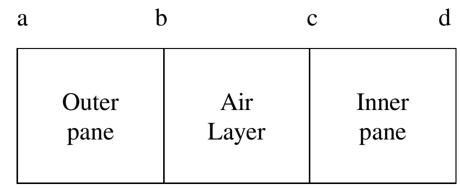

Figure 1: Double-Paned Glass Structure

Table 2 shows the optical nature and heat efficiency of double-paned glasses produced by KCC in terms of November 2005. The KCC is one of famous glass manufacturers in South Korea.

The U-value or heat transfer coefficient, is the measured heat flow which is transferred through an area of 1 square meters at a temperature difference of 1K. The lower the U-Value, the more restrictive the fenestration product is to heat transfer. Shading Coefficient is the measure of the amount of heat passing through the glazing compared with that through a 3 ㎜ single plain glass under the same conditions.

Solar Radiation in Table 2 is measured at right incidence angle (90°) on a single plain glass. Also transmittance is the authentic value and the tolerance is ±3%. U-Value and Shading Coefficient are measured by the Window 5.2 program and based on the Korean Standard (KS). U-value is calculated based on the winter season.

Table 2: Optical Nature and Heat Efficiency of Double-Paned Glass

Glass Type	Components	U-value [W/㎡ K]	Shading Coefficient	Solar Radiation [Transmittance, %]
Clear Double-Paned Glass	5+6A+6	3.32	0.80	59
	6+6A+6	3.29	0.78	59
	6+12A+6	2.87	0.78	55
Clear Low-E Double-Paned Glass	6+6A+|6	2.54	0.64	41
	6+12A+|6	1.74	0.64	41

2.2 Basic Data Assumption for LCC Analysis

The factors considering in the LCCA of this study are the analysis period (service life), discount rate (time value of money), initial cost, and maintenance cost. The present worth method is used to calculate the LCC of the double-paned glass in this research.

2.2.1 Analysis Period (Service life) in a Multi-Family Housing Project

In this research, the double-paned glass is assumed to be replaced at the end of service life for a multi-family housing project. Therefore, it is important to establish the point at which a multi-family housing project is reconstructed or remodeled in the LCCA of double-paned glass. The end of service life of a multi-family housing project is assumed to be 20 years. The reason for this is that the multi-family housing project can be only reconstructed or remolded at 20-year period after its initial construction according to the housing law enforced by South Korea. In addition to those, the study conducted by Jung and Seo (2002) showed that the long-term repair cost is significantly increased at 20 years in a high-rise multi-family housing due to the accumulated annual repair or replacement cost of a building's components or plumbing materials (Jung and Seo 2002).

2.2.2 Real Discount Rate (Time Value of Money)

For the LCCA of double-paned glass, the real discount rate not considering inflation is used in this research. According to the report by the Korea Development Institute (2004), the 6.0% is the most appropriate for the real discount rate in South Korea. Also, the 6.0% is considered as the real discount rate for this research.

3. Estimation Criteria of LCC of Double-Paned Glass

3.1 Estimation Criteria of Initial Cost

Initial cost includes the material price and the double-paned processing cost. Table 3 shows the cost of double-paned glass produced by KCC in terms of November 2005.

Table 3: Price and Cost of Double-Paned Glass (Unit: □/㎡)

Type	Thickness	Components	Material Price		Double-Paned Processing Cost	Total
			Outer Paned	Inner Paned		
Clear Double-Paned Glass	16T	5+6A+5	6,600	6,600	5,600	18,800
	18T	6+6A+6	8,400	8,400	6,300	23,100
	24T	6+12A+6	8,400	8,400	10,500	27,300
Clear Low-E Double-Paned Glass	18T	6+6A+l6	8,400	29,400	11,200	49,000
	24T	6+12A+l6	8,400	29,400	16,800	54,600

3.2 Estimation of Energy Cost using ENERGY-10 Program

To quantitatively evaluate the energy performance of the building by using the energy consumption data of the case, this research applied the ENERGY-10 program which was developed as part of the Optimization of Solar Energy in Larger Building, Solar Heating & Cooling TASK 23 of IEA (International Energy Agency) (Balcomb and Corwder 1995).

ENERGY-10 is the result of a collaborative project of the NREL (National Renewable Energy Laboratory) Center for Building and Thermal Systems, the Sustainable Buildings Industry Council (SBIC), the Lawrence Berkeley National Laboratory (LBNL), and the Berkeley Solar Group (BSG). It is useful for determining materials and sizes at the design stage by estimating building energy consumption and energy saving from a sustainable architecture design method (ENERGY-10).

3.3 Case Selection

To estimate the energy cost by the glass type of this study, this research selected the most typical type, the multi-family housing of the nettable area of a total of 84 square meters located in Seoul, South Korea as a case study which is composed of 12 stories

3.3.1 Floor Plan

In the case of a more or less than nettable area of a total of 85 square meters, the floor plan comprised of 3BLDK has become a most typical type which used in this research (refer to Figure 2).

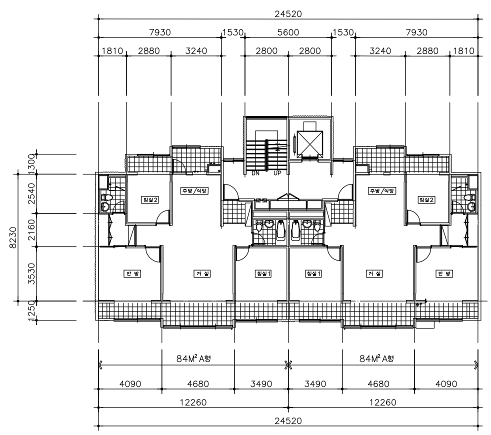

Figure 2: Floor Plan

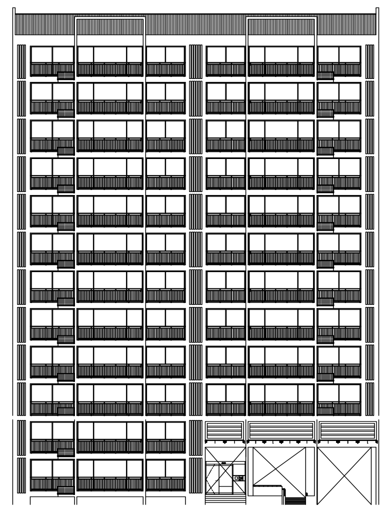

Figure 3: Section Plan

3.3.2 Section Plan

The heat load of a multi-family housing is different depending on the position of a housing unit and story. This research has not analyzed an individual housing unit but the entire multi-family housing building with regard to section plan since the energy consumption is analyzed by ENERGY-10 simulation. In the most multi-family housing projects, only south and north facades of housing units are directly facing to the air. Thus it is more accurate to analyze the energy loss by applying the mean value of the energy consumption of the entire multi-family housing building (Moon 2002).

This study analyzed the entire building shown in Figure 3. To facilitate the simulation, the main entrance part is assumed as two housing units, and thus, the energy consumption of a total of 24 housing units was analyzed.

3.3.3 Case Analysis

The energy consumption of this case was simulated by the ENERGY-10 (Version 1.5) program. The settings of each element of this case for simulation are presented in Table 4.

Table 4: Data for ENERGY-10 program

Element	Setting	Element	Setting
Floor Area	287.62 m^2	Height	34.45 m
North-South Facades	1,647.74 m^2	East-West Facades	788.26 m^2
Wall Gross Area	609.77 m^2	Floor Gross Area	3,451.44 m^2
Front Balcony Area	575.28 m^2	Back Balcony Area	167.04 m^2
HVAC Operation Hour	Always-On	Heating Setpoints	20□
Lighting	12.9W/ m^2	Occupancy	4 People in each housing unit
Exterior Wall	Concrete (180) – EPS Foam (95) – Gypboard (12.5)		
Floor	Concrete (180) – EPS Foam (20) – Stone(50) – Cement (42) – Softwood (8)		
Interior Wall	Concrete (160) – EPS Foam (70) – Gypboard (12.5)		
Roof	Concrete (150) – EPS Foam (100) – Concrete (100)		

4. LCC Analysis of Double-Paned Glass Type

4.1 Initial Cost

The areas of the front and back balcony windows for the each housing unit were 23.97 m^2 and 6.96 m^2, respectively. Then, the total areas of both balcony windows were 575.28 m^2 (23.97 m^2 * 24 housing units) and 167.04 m^2 (24 housing units * 6.96 m^2) in the entire multi-family housing building. Table 5 shows the initial cost of two representative glass types.

Table 5: Initial Cost by Glass Type (Unit: ₩)

Back Balcony Glass Type	Front Balcony Glass Type		Glass Price / m^2 + Double-Paned Processing Cost / m^2		Initial Cost
			Back	Front	
Clear Double-Paned Glass 16T	Clear Double-Paned Glass	16T	18,800	18,800	13,955,616
Clear Low-E Double-Paned Glass 24T	Clear Low-E Double-Paned Glass	24T	54,600	54,600	40,530,672

4.2 Energy Cost

Table 6 shows the energy rate of both electricity and gas used in this research. The electricity rate is the current price on the low voltage of houses obtained from Korean Electric Power Corporation in 2006 and Gas price is also the current price obtained from Seoul City Gas in 2006.

Table 6: Energy Rate

Type of Energy	Basic Rate	Type	Rate
Electricity	□3,420	Under 100kWh	55.10 (□/kWh)
		101□200kWh	113.80 (□/kWh)
Gas	None	Winter Season (Nov ~ Apr)	477.73 (□/m3)

Table 7 presents the energy consumption and the cost of the each alternative. The annual energy cost can be saved by □9,226,908, provided that the Low-E Double-Paned Glass 24T are used instead of being used clear Double-Paned Glass 18T which is the most typical type used for both sides (front and back) of the balcony windows in multi-family housing projects. If the annual saving is calculated in terms of the 20-year period, the total energy saving would be □105,831,908 for the service life of a multi-family housing project.

Table 7: Energy Cost Comparison by Glass Type

Back Balcony Window Type	Front Balcony Window Type	Amount of Used Energy (Mcal)		Energy Cost (□)		Annual Energy Cost (□)	Energy Cost for 20-year period (□)
		Electricity	Gas	Electricity	Gas		
Clear Double-Paned Glass 18T	Clear Double-Paned Glass 18T	117,124	2,087,407	218,973	127,550,982	127,769,955	1,465,511,318
Clear Low-E Double-Paned Glass 24T	Clear Low-E Double-Paned Glass 24T	111,796	1,936,591	207,675	118,335,372	118,543,047	1,359,679,410

4.3 Results of LCCA

Table 8 shows the results of the LCCA. It was found that the clear Low-E Double-Paned Glass 24T was ranked as the lowest LCC in the balcony windows. In other word, the clear Low-E Double-Paned Glass 24T is the most economical selection for both sides of the balcony windows.

Table 8: LCC by Glass Type

Back Balcony Window Type	Front Balcony Window Type		Initial Cost (□)	Energy Cost (□)	Total (□)
Clear Double-Paned Glass 16T	Clear Double-Paned Glass	16T	13,955,616	1,459,262,080	1,473,217,696
		18T	16,429,320	1,465,386,181	1,481,815,501
		24T	18,845,496	1,432,638,788	1,451,484,284
	Clear Low-E Double-Paned Glass	18T	31,329,072	1,448,479,437	1,479,808,509
		24T	34,550,640	1,391,996,475	1,426,547,115
Clear Double-Paned Glass 18T	Clear Double-Paned Glass	16T	14,673,888	1,459,957,949	1,474,631,837
		18T	17,147,592	1,465,511,318	1,482,658,910
		24T	19,563,768	1,432,786,107	1,452,349,875
	Clear Low-E Double-Paned Glass	18T	32,047,344	1,448,494,485	1,480,541,829
		24T	35,268,912	1,392,078,290	1,427,347,202
Clear Double-Paned Glass 24T	Clear Double-Paned Glass	16T	15,375,456	1,449,717,603	1,465,093,059
		18T	17,849,160	1,455,919,917	1,473,769,077
		24T	20,265,336	1,423,178,374	1,443,443,710
	Clear Low-E Double-Paned Glass	18T	32,748,912	1,438,722,984	1,471,471,896
		24T	35,970,480	1,382,411,567	1,418,382,047
Clear Low-E Double-Paned Glass 18T	Clear Double-Paned Glass	16T	19,000,224	1,443,068,272	1,462,068,496
		18T	21,473,928	1,449,504,171	1,470,978,099
		24T	23,890,104	1,416,611,591	1,440,501,695
	Clear Low-E Double-Paned Glass	18T	36,373,680	1,432,471,063	1,468,844,743
		24T	39,595,248	1,375,889,666	1,415,484,914
Clear Low-E Double-Paned Glass 24T	Clear Double-Paned Glass	16T	19,935,648	1,427,141,105	1,447,076,753
		18T	22,409,352	1,433,184,010	1,455,593,362
		24T	24,825,528	1,400,393,960	1,425,219,488
	Clear Low-E Double-Paned Glass	18T	37,309,104	1,415,616,312	1,452,925,416
		24T	40,530,672	1,359,679,410	***1,400,210,082***

5. Sensitivity Analysis under different discount rate and service life

5.1 LCC Variations by Real Discount Rate and Service Life

The sensitivity analysis on the variation of LCC is conducted under the different real discount rates of 5.2%, 5.7%, 6.2%, and 6.5%, respectively. In case of a 6.0% real discount rate and the service life of 20-year period, the LCC difference between Double-Paned Glass 18T and Low-E Double-Paned Glass 24T for both front and back balcony window was ₩82,448,828 (₩1,482,658,910 for clear Double-Paned Glass 18T - ₩1,400,210,082 for clear Low-E Double Paned Glass 24T) as shown in Table 9.

Table 9: LCC in case of a 6.0% Real Discount Rate and a 20-year service life

Real Discount Rate	Back Balcony Window Type	Front Balcony Window Type		Initial Cost (₩)	Energy Cost (₩)	Total (₩)
6.0%	Clear Double-Paned Glass 18T	Clear Double-Paned Glass	16T	14,673,888	1,459,957,949	1,474,631,837
			18T	17,147,592	1,465,511,318	***1,482,658,910***
			24T	19,563,768	1,432,786,107	1,452,349,875
	Clear Low-E Double-Paned Glass 24T	Clear Low-E Double-Paned Glass	18T	37,309,104	1,415,616,312	1,452,925,416
			24T	40,530,672	1,359,679,410	***1,400,210,082***

Based on the different service life of 20, 25, 30, 35, and 40 years and a 6.0% real financial discount rate, the LCC variations are analyzed. Due to editorial constraint, Table 10 shows only the LCC result for the 40-year life cycle and a 6.0% real financial discount rate. In case of a 6.0 % real discount rate and the service life of 40-year period, the LCC difference between Double-Paned Glass 18T and Low-E Double-Paned Glass 24T for both front and back balcony window was ₩115,447,717 (₩1,939,612,266 for clear Double-Paned Glass 18T - ₩1,824,164,549 for clear Low-E Double Paned Glass 24T) as shown in Table 10.

Table 10: LCC in case of a 6.0% Real Discount Rate and 40-year service life

Service Life	Back Balcony Window Type	Front Balcony Window Type		Initial Cost (₩)	Energy Cost (₩)	Total (₩)
40 yr	Clear Double-Paned Glass 18T	Clear Double-Paned Glass	18T	17,147,592	1,922,464,674	***1,939,612,266***
			24T	19,563,768	1,879,535,588	1,899,099,356
	Clear Low-E Double-Paned Glass 24T	Clear Low-E Double-Paned Glass	18T	37,309,104	1,857,012,169	1,894,321,273
			24T	40,530,672	1,783,633,877	***1,824,164,549***

5.2 Result of Sensitivity Analysis

As mentioned in the result of the sensitivity analysis based on the glass type, the energy cost is significantly changed according to the change of the real discount rate and the building service life. Therefore, Low-E Double-Paned Glass 24T was ranked as the most economical glass type for both front and back sides of the balcony windows in all cases of different real discount and building service life.

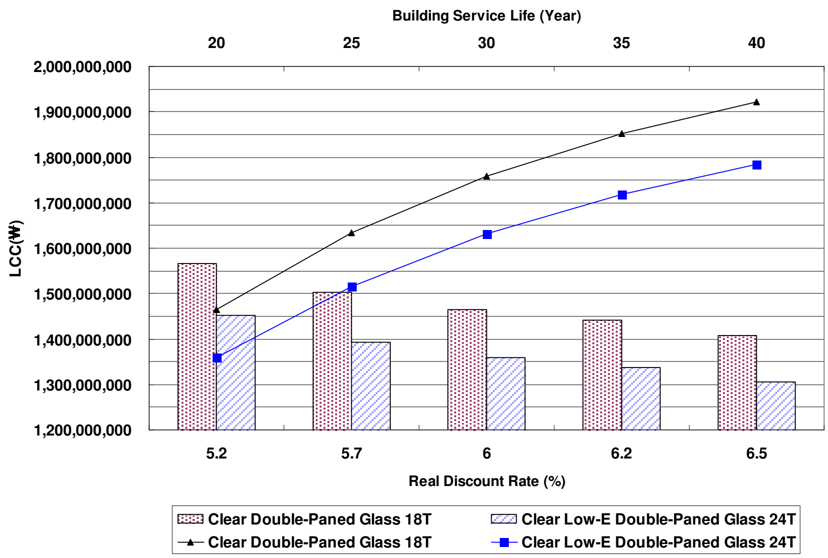

Figure 4: Result of Sensitivity Analysis (Present Worth Method)

Figure 4 shows the result of sensitivity analysis with regard to LCC of Double-Paned Glass 18T and Low-E Double-Paned Glass 24T based on the different service lives and real discount rates. The bar graph shows the result of the real discount rate variations and the line graph shows the result of the building service life variations.

Figure 4 shows that the selection of Low-E Double-Paned Glass 24T is approximately □80million more economical than that of Double-Paned Glass 18T for both sides of the balcony window, provided that a service life of 20-year and 6.0% real discount rate are used, and the selection of Low-E Double-Paned Glass 24T is approximately □115million more economical, provided that a service life of 40-year and 6.0% real discount rate are used. As the service lives of multi-family housing increased, the difference of LCC by glass type also increased. If the heat efficiency decreases due to the deterioration of each item and plumbing materials of the building, the difference of LCC between Low-E Double-Paned Glass 24T and Double-Paned Glass 18T will increase beyond the results shown in this research.

6. Conclusion

This study has analyzed the economical efficiency of the glass type of the balcony window in the most typical type of the multi-family housing in metropolitan area, based on the assumption that the balcony is converted.

Based on the result of the LCC analysis by glass type in the selected case study, clear Low-E Double-Paned Glass 24T provided the most economical efficiency for the both front and back sides of the balcony window.

To be sure, a reader should consider about the results because this research begins with assumptions, which some might affect the results of this research.

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