Hindawi
International Journal of Polymer Science
Volume 2017, Article ID 8681737, 9 pages
https://doi.org/10.1155/2017/8681737

Research Article

Establishment of Passive Energy Conservation Measure and Economic Evaluation of Fenestration System in Nonresidential Building of Korea

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Received 21 October 2016; Accepted 21 December 2016; Published 16 March 2017

Academic Editor: Geun Y. Yun

ECO2 (building energy efficiency rating program) and passive energy conservation measures (ECMs) were established as a basic study for targeted methodologies and decision support systems development in Korea to meet national regulations. The primary energy consumption and economic evaluation of nonresidential buildings was performed. Passive ECMs were classified as planning and performance elements. The planning elements are the window-to-wall ratio (WWR) and horizontal shading angle. The performance elements are the thermal transmittance (U-value) of the walls, roof, and floor and the U-value and solar heat gain coefficient (SHGC) of windows. This study focused on the window-to-wall ratio and the U-value and solar heat gain coefficient of windows. An economic efficiency database for the constructed alternatives was built; the target building was set and the Passive ECM List for the target building was derived. The energy consumption evaluation and economic evaluation were performed for each of the constructed alternatives, and a methodology for guiding energy efficiency decisions was proposed based on the performance evaluation results, and the optimal Passive ECM List for the target building was derived.

1. Introduction

Nowadays, because of climate change, the reduction of greenhouse gas emissions and energy conservation is emphasized globally. The government announced the 30% reduction goal based on the greenhouse gas emission projection for 2020 and enacted the Framework Act on Low Carbon, the Green Growth in April, 2010 [1]. Considering the international responsibility of South Korea, the government intensified the reduction goal of greenhouse gas emissions for 2030 as 37% and are proceeding with the objectives established according to sectors, occupations, and years to achieve the goal [2]. In building sector, *the Support System for Composition of Green Architectures* [3] which determines matters for the creation of green buildings and aims to reduce CO2 emissions of buildings and expand green buildings and *Building Design Criteria for Energy Saving* [4] were enacted and announced, and energy conservation and efficiency management including the performance evaluation system of eco-friendly homes are being carried out for the overall aspects of new and existing buildings from the building design to the building operation in response to these measures.

On the other hand, although "Green Together," a web portal for green buildings in Korea, provides information on green buildings, an evaluation and comparison of energy efficiency measures as a targeted methodology have not been established [5]. Therefore, it is necessary to develop the support system that provides effective building-related information and can be applied and evaluated for energy efficiency alternatives.

To reduce greenhouse gas emissions and improve the distribution and activation of green buildings, the government of South Korea is implementing a number of standards and systems for strengthening the criteria for new and existing buildings. Among them, the purpose of the Building Design Criteria for Energy Saving is to determine the items related to the energy-saving design criteria, including heat loss prevention, writing standards of energy conservation plans, and design review reports. In addition, the system aims to relax the construction standards to promote the construction of green buildings, for efficient energy management of buildings in accordance with the Support System for Composition of Green Architectures.

It is mandatory to submit an energy conservation plan at the time of the application for permission to construct or change the use of buildings with a gross floor area of 500 m^2 or more (excluding single-family homes, zoos, and botanical gardens), and a review report of the energy conservation plan design is composed of mandatory items (19 items of the sectors of construction, machinery, and electricity) and recommendations (51 items of the sectors of construction, machinery, electricity, and new and renewable energy). The adoption of all mandatory items and the acquisition of at least 65 points of the energy performance index (EPI) or the acquisition of at least 74 points of the energy performance index (EPI) for public buildings are prescribed as the requirements for a suitability determination. In addition, in the case of office buildings with a gross floor area of 3,000 m^2 or more, a report of the building energy consumption evaluation by a simulation of the ECO2-OD must be submitted.

The Building Design Criteria for Energy Saving have been partially amended ten times since the enactment of the number 2008-5 based on the current number 2015-596 (effective 8/17/2015). As a result of partial revisions of the number 2014-520, the mandatory items of the construction sector were added to the number 2014-957, the construction sector items for nonresidential buildings in the energy performance index were added, and the scoring range of item 8 (concerning the installation of the shading devices of south-facing and west-facing windows) was revised. As a result of the addition of construction sector items, the sum of the basic scores was 50 points for large nonresidential buildings and 66 points for small nonresidential buildings. Therefore, the basic scores of the construction sector for small nonresidential buildings are 16 points higher than those of large buildings. The main amendments include the addition of a regulation that requires the mandatory installation of shading devices for 10% or more of the south and west window areas (0.6 points or more) in public buildings with a gross floor area of 3,000 m^2 or more, including public institutions and educational institutions. In addition, thermal insulation standards are expected to be strengthened to the level of advanced countries to ensure the basis of the mandatory implementation of Passive Buildings of 2017. (For example, external wall insulation standards will be strengthened by 28.6% from 0.27 W/m^2 K to 0.21 W/m^2 K in the central region of the country.)

The ECO2, which was used as the energy efficiency rating of domestic buildings, has been developed as a program suitable for domestic situations based on the DIN V 18599 of Germany with reference to the EN ISO 13790, EN 15203, and so forth [5]. This is a program for analyzing the energy required to maintain the indoor environment of a building suitable for the use of that building. Using this program, the primary energy demand, energy consumption, and carbon dioxide emissions of a building can be predicted based on the energy values calculated by quantitative analysis of the energy required for heating, cooling, lighting, hot water, and ventilation taking into consideration the interaction of energy flows depending on characteristics of building construction.

The building information of ECO2 distinguishes 13 regions, and the information was divided and evaluated separately according to the use and size of the buildings. The input data taps are largely divided into the sectors of building construction, M/E equipment, and new and renewable energy. The construction sector includes the items of the input surface, input zone, U-value, and the machinery sector. In addition, the new and renewable energy sector is divided into renewable and cogeneration and the information for each category is entered and evaluated separately. The input taps related to the construction sector (Passive) that this study is intended to focus on and suggest are divided into the input zones for entering information on the space for which the load is analyzed and the input surfaces for evaluating the U-values, heat loss, and heat gain concerning the thermal performance of building envelopes and an evaluation of heat loss and heat gain.

Yaşar and Kalfa [6] examined the effects of alternative units, rather than readily available double-glazed units, in two types of flats to determine the influence of the windows on the energy consumption and economy of high-rise buildings. The simulation shows that smart-glazed units and those with low emissivity glazing are the most efficient alternatives with regard to a building's energy consumption and economy. Tian et al. [7] reported a generalized window energy rating system for typical office buildings. In their study, to demonstrate how a WERS in a particular location can be established and how well the model can work, the model and approach were applied to a typical office building of Hong Kong as an example. Kim et al. [8] proposed the supplement point of Korea's policies and guidelines regarding windows through a comparison of Korea's policies and guidelines for windows. In addition, they checked the variation of the energy consumption of buildings through a variation of the window elements and proposed an energy analysis indicator for the Republic of Korea. Koçlar Oral [9] compared the calculated daily average hourly heat loss per unit area of building envelopes with different window types to determine the appropriate window type from a heating energy conservation viewpoint. Persson et al. [10] examined how decreasing the window size facing south and increasing the window size facing north in these low energy houses would influence the energy consumption and maximum power required to maintain an indoor temperature between 23°C and 26°C. The results showed that the size of the energy efficient windows does not have a major influence on the heating demand in winter but is relevant for the cooling needs in summer. This suggests that instead of the traditional way of building passive houses, it is possible to enlarge the window area facing north and achieve better lighting conditions. Yeom et al. [11] investigated the 7 performance categories

Table 1: U-values and g-values (SHGC) for windows.

U-value/g-values for windows							
1.16/0.25	1.19/0.21	1.23/0.33	1.54/0.24	1.57/0.22	1.62/0.57	1.63/0.34	1.65/0.33
1.67/0.40	1.73/0.59	1.78/0.61	1.90/0.40	2.85/0.46	2.85/0.52	2.85/0.73	—

of domestic windows for an apartment house, examined the energy-saving effects according to the window thermal performance, and estimated the window economic efficiency. As in previous studies, many studies have been conducted to save energy for windows worldwide. However, in Korea, information on alternatives and technologies for building energy conservation measures are dispersed and concrete methods are not built up, so it is difficult to apply effective alternatives.

In this study, energy efficiency alternatives (ECM List) were constructed focusing on the construction sector (Passive) as the basis for a targeted methodology and the decision support system development for a domestic situation. An economic efficiency database for the constructed alternatives was built; the target building was set and the Passive ECM List for the target building was derived. An energy consumption evaluation and economic evaluation were performed for each of the constructed alternatives, and this paper proposes a methodology for guiding energy efficiency decisions, based on the performance evaluation results, and derives the optimal Passive ECM List for the target building.

2. Development of ECM List and Economic Efficiency Database

2.1. ECM List. A brief examination of the input items of the construction sector of the ECO2 and their properties to establish building energy efficiency alternatives (Passive ECM List) for a domestic situation showed that the input categories of the construction sector of the ECO2 are composed of the following: input zones, input surfaces, and U-values. These were divided into the categories for which the thickness or a value is entered directly and those with some given options are selected and applied. The ECO2 does not include a separate input category for the window-to-wall ratio, but the window area is entered and evaluated for each zone. The window-to-wall ratio should be considered before the other items because it affects other energy efficiency alternatives of the Passive ECM List.

2.1.1. Window-to-Wall Ratios. Among the planning factors, the window-to-wall ratio should be considered first because it affects the other elements. The window-to-wall ratio is the proportion of the window area to the total area of the exterior envelope, and its range was set by dividing the ratios into 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, and 80%.

The mean U-value of the external walls of buildings (including windows and doors) varies according to the window-to-wall ratio. Moreover, because the average U-value of the external walls is a mandatory item in an energy conservation plan and its maximum value is prescribed according to regions, the window-to-wall ratio that satisfies the criterion by not exceeding the average U-value for the external walls is derived as the alternative for the target building.

2.1.2. U-Values and G-Values of Windows. In the ECO2 program, the U-values and solar energy transmittance (G-values) of windows are entered and evaluated directly. Although basic options are offered for the kinds of insulating materials of walls, roofs, and floors, the options to be selected and applied are not provided for windows, so the values for the window performance must be entered directly. Therefore, the common values concerning the window performance were constructed from the information obtained from a company that produces windows and doors. The product information is about the general pair glass windows, and it provides information on the general pair glass and low-e pair glass, as shown in Table 1.

2.2. Economic Evaluation

2.2.1. Economic Evaluation Database. The database for an economic evaluation of energy efficiency measures for buildings is composed of investment costs and operating costs. Investment costs include the material costs, labor costs, and expenses, while the operating costs are the expenses used to operate the building and consist of maintenance expenses, dismantling and demolition costs, and energy costs. Table 2 presents the method of building an economic evaluation database and the items that constitute it.

(1) Initial Investment Cost. The investment cost in an economic evaluation database for nonresidential buildings refers to the simple establishment expense required when constructing a building and it is calculated as the sum of the costs of materials, labor, and expenses. The indirect labor costs and expenses for economic evaluation are calculated as the ratios, as presented in Table 3.

(a) Labor Cost. The labor costs of the initial cost are divided into direct and indirect labor costs; the direct labor costs are calculated by reference to the "standard market unit price" of the Public Procurement service, and the indirect labor costs are calculated by reference to the criteria for the application of expense ratios in construction cost calculations.

(b) Expenses. The expenses of the initial investment cost are the costs incurred by the consumption of the cost items other than materials and labor cost, and they are calculated by reference to "the criteria for application of expense ratio in construction cost calculation." Their components are other expenses, worker's compensation insurance, health pension

Table 2: Method of building the economic evaluation database and the item.

Division	Sort	DB source	DB building item
Initial investment cost	Material cost	Korea Price Information	Material cost
	Labor cost	Standard market unit price: the criteria for application of expense ratios in construction cost calculation	Labor cost per m^2
	Public expenditure		Public expenditures per m^2
Operating cost	*Maintenance expense*		
	Maintenance cycle	Housing Act enforcement regulations: the criteria for long-term repair plan establishment	Maintenance cycle
	Maintenance rate		Rate of repairing level
	Energy expense		
	Electricity	Korea electric power corporation	The year rates
	Town gas	Regional natural gas supplier	The year rates
	District heating	Korea district heating corporation	The year rates

Table 3: Method for calculating the investment costs DB for an economic evaluation.

Labor cost	Direct labor cost	Direct labor cost × rate	Construction	7.6
			Industrial facility	7.6
Expenses	Other expenses	(Material cost + labor cost) × rate	Construction	6.4
			Industrial facility	6.4
	Worker's compensation insurance	(Labor cost) × rate		1.01
	Health pension insurance	(Direct labor cost) × rate		[Health]: 1.7 [Pension]: 2.49
	Long-term care	(Health insurance) × rate		6.55
	Environmental preservation cost	(Material cost + direct labor cost) × rate		0.8
	Retirement costs deductible installment	(Direct labor cost) × rate		2.3

insurance, long-term care insurance, environmental preservation cost, and retirement costs deductible installment.

(2) Operating Costs

(a) Maintenance Expenses. Maintenance expenses are costs used for the maintenance and management of a building and they are calculated as the sum of the repair cost and replacement cost. The repair and replacement cost can be estimated based on the repair or replacement cycle and rate. Table 4 lists a part of the criteria for long-term repair plan establishment in the Housing Act enforcement regulations [effective 01/07/2015].

(b) Energy Costs. Energy costs are composed of electricity, city gas, and district heating. For electricity costs, which are part of the energy costs, the rates provided by the Korea Electric Power Corporation were applied. The electricity rates for nonresidential buildings were classified into those for general purposes, for industrial use, and for educational use, and the electric power rates depend on the contract power. The electricity rates are divided into those for a contract power of less than 300 kW (A type) and those for a contract power of 300 kW and more (B type). The electricity rates are calculated using formula (1).

The city gas rates vary from region to region, and the rates offered by local natural gas suppliers are applied. The city gas rates for nonresidential buildings are divided into those for business heating, for HVAC, for commercial use, for industrial use, and for social welfare use depending on the types of use, and city gas charges are calculated using formula (2). The average calories used to calculate the city gas prices refer to the monthly weighted average calories of a specific period [MJ/Nm^3].

For district heating charges, the rates provided by the Korea District Heating Corporation were applied.

$$\begin{aligned}\text{Electricity price} &= (\text{basic price} + \text{usage charge} - \text{welfare discount}) \\ &\quad \times \text{VAT}\ (10\%) \\ &\quad \times \text{Electric Power Industry Basic Fund}\ (3.7\%)\,,\end{aligned} \tag{1}$$

$$\begin{aligned}\text{city gas price} &= (\text{used amount} \times \text{correction factor}) \\ &\quad \times \text{average calories} + \text{replacement cost} + \text{VAT}.\end{aligned} \tag{2}$$

Table 4: Repair and replacement cost of windows.

Construction type	Method of repair	Maintenance cycle	Maintenance rate	Note
Steel windows and doors	Window and door frame repairs	10	20	Except windows hardware
	Window and door repair	10	20	
	Full replacement	30	100	
Aluminum windows and doors	Window and door frame repairs	10	10	Except windows hardware
	Window and door repair	10	20	
	Full replacement	25	100	
Painting oil paint	Full coat	5	100	Steel parts
	Full rust preventive	5	100	
Painting synthetic resin paint	Full coat	6	100	Steel parts
	Full rust preventive	12	100	

2.2.2. LCC Evaluation. The LCC evaluation is a method for evaluating and analyzing the total costs incurred from the planning and design stage to the construction (installation), operation, and the dismantling and demolition stage after use. To analyze the costs incurred at various points, such as the initial investment cost, energy cost, operating cost, and dismantling and demolition costs, all costs should be converted to the values at the same point in time. When future costs are converted to the present value, a discount rate is applied, and when the present value is converted in a future value, an interest rate is applied. By applying the real discount rate to the total costs incurred during the evaluation period, the LCC (life cycle cost) is calculated, as shown in

$$\text{LCC} = \text{IC} + \text{OCpv} + \text{DCpv} = \sum_{t=0}^{n} \frac{Ct}{(1+d)^t}, \tag{3}$$

where IC is the initial investment cost, OCpv is the present value of total operating cost, DCpv is the present value of dismantling and demolition cost, d is the real discount rate, and Ct is all costs incurred in the year t.

The real discount rate can be calculated by distinguishing between the nominal cash flow and real cash flow. If inflation is expected, the interest rate determined by adding the inflation rate to the real interest rate is applied, and it is referred to as the nominal interest rate for nominal cash flow. The nominal interest rate is calculated using

$$R = (1 + r)(1 + \text{inf}), \tag{4}$$

where R is the nominal interest rate, r is the real interest rate, and inf is the inflation rate.

For the real cash flow, the real interest rate is calculated using (5) and is used as the discount rate.

$$r = \frac{(1 + R)}{(1 - \text{inf})} - 1. \tag{5}$$

All costs for the economic efficiency evaluation in this study were calculated per unit area (m^2).

To calculate the labor costs for the installation of windows, the labor cost per unit area for the installation of pair glass was applied (50,535 won/m^2 based on the glass specification of (6+12A+6)). In the energy consumption results of ECO2, the energy for heating and hot water was calculated by applying the city gas rates, and for the energy of air conditioning, lighting, and ventilation, the energy costs were calculated by applying the electric power rates. The city gas rates were calculated using the method for calculating the rates for heating for business use in Seoul. The electric rates are divided into A and B types according to the contract demand of the building. The selection rate system with the options of (I), (II), and (III) was implemented and the rates were calculated by dividing time zones depending on the loads. In this study, electricity rates were calculated by applying the average electricity rate during the summer months of 105.3 won/kWh for the general power rates (A).

Table 5: Overview of the target building.

Category	Description
Region	Seoul
Use	Office building
Structure	Reinforced concrete
Size	1 floor under ground 3 floors above ground
Gross floor area	2,325 m^2

3. Performance Evaluation for Each Alternative of the ECM List

3.1. The Overview of the Target Building. A general business building has a gross floor area of 2,325 m^2 and of the reinforced concrete structure that has three floors above ground and consists of offices, meeting rooms, seminar rooms, and so forth. The workspaces used mainly in the target building are placed on the south and north side and the staircases and toilets are located on the west side. Table 5 presents an overview of the target building, and Table 6 provides information on the envelope performance of target buildings.

Table 6: Envelope performance of target building.

Building component	Performance	
	U-value	SHGC
Wall (direct)	0.244	—
Root (direct)	0.165	—
Floor (direct)	0.254	—
Floor (indirect)	0.237	—
Window (indirect)	2.4	0.77
Window (direct)	2.0	0.40
Window (direct)	1.9	0.40

3.2. ECM List for the Target Building

3.2.1. Window-to-Wall Ratios. Among the planning factors, the window-to-wall ratio should be considered first because it affects the other elements. As the window-to-wall ratio is increased, the mean U-value of the external wall increases, and the average U-value of the external wall must be less than 1.180 W/m^2·K in the central region, which is a mandatory item of the energy-saving plan. Therefore, when the window-to-wall ratio of the target building is increased, it is derived within the range that satisfies the criterion of the average U-value. For the window areas, the areas of the south-facing and north-facing windows were increased in accordance with the window design guidelines.

3.2.2. U-Values and g-Values (SHGC) of Windows. Because the U-value criterion of 2.1 W/m^2·K or less for the windows of the target building that are exposed to the outdoor air directly must be met, 12 alternatives were derived. The windows in the target building were composed of those in the main entrance, halls, lobbies, and main business areas, and the application and evaluation were conducted only for the windows of the business areas.

3.3. Energy Consumption Evaluation. For the alternatives of each of the planning and performance factors for the target building, the primary energy consumption was evaluated using the building energy efficiency rating program (ECO2) and impact analysis was carried out. In the domestic building energy efficiency rating, the energy consumption for cooling was not assessed or considered in the case of residential buildings, but for nonresidential buildings, the total energy consumption according to each load was considered, which allowed an analysis of the total energy consumption, including energy consumption for cooling and heating.

3.3.1. Window-to-Wall Ratios. Among the planning factors that should be considered primarily, Figure 1 presents the primary energy consumption of the target building according to the window-to-wall ratios. The total primary energy consumption according to the window-to-wall ratio shows that

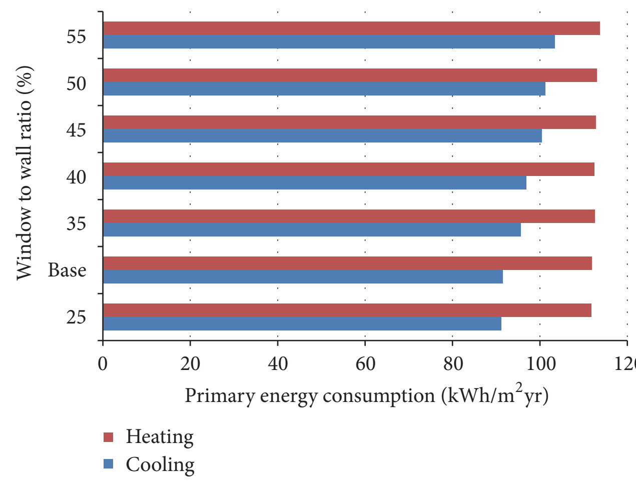

Figure 1: Primary energy consumption for cooling and heating according to the window-to-wall ratio of the target building.

the primary energy consumption increases with increasing window-to-wall ratio. Both the cooling and heating energy are increased with increasing window-to-wall ratio. Although the growth rate of heating energy was small, the cooling energy increased considerably. Thus, in terms of energy consumption, it is efficient not to increase the window-to-wall ratio. Therefore, in this study, the window-to-wall ratio of the target building was maintained without increasing it when the energy consumption evaluation for other alternatives was performed.

3.3.2. U-Values and g-Values (SHGC) for Windows. To establish the energy efficient alternatives according to the performance of windows, 12 alternatives that meet the regulatory criterion of 2.1 W/m^2·K or less for the windows that are exposed directly to the outside air were constructed, including the original plan of the target building; Figure 2 presents the primary energy consumption.

In this study, the evaluation results of the energy consumption depending on the increase in window-to-wall ratio of the target building by utilizing ECO2 showed no energy-saving effect, and the window-to-wall ratio of the target building was maintained without changing it in the evaluation of other alternatives of the Passive ECM List. Figure 2 presents the total primary energy consumption according to the window-to-wall ratios of horizontal shading devices.

3.4. Economic Evaluation. The window is an element that affects the energy consumption by its two performances, that is, its U-values and g-values, so the LCC and energy costs according to the performances were calculated. Figure 3 shows the LCC according to the window performance. Figure 4 presents the LCC depending on the primary energy consumption according to the window performance. Compared to the original plan, the alternative showing a

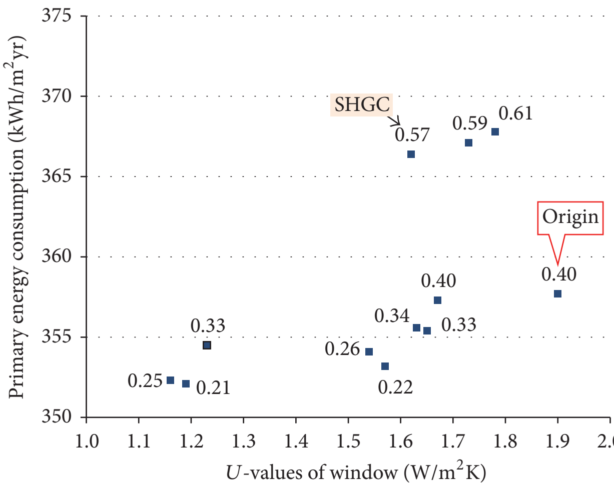

FIGURE 2: Primary energy consumption according to the window performance of the target building.

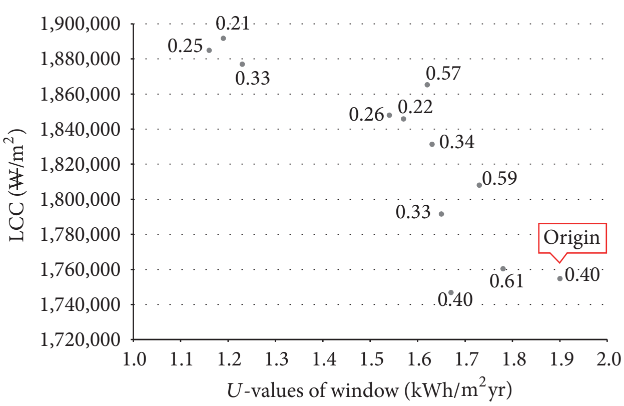

FIGURE 3: LCC according to the window performance.

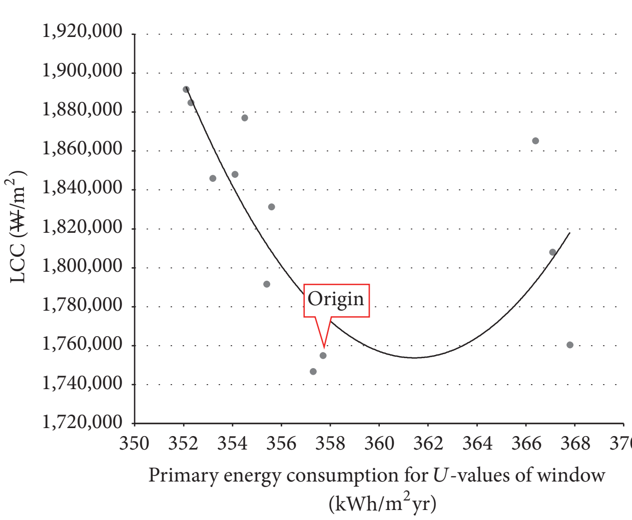

FIGURE 4: LCC depending on the primary energy consumption according to the window performance.

decrease in both primary energy consumption and LCC was derived.

4. Building Energy Efficiency Decision Support Process

There are diverse conditions for making decisions based on the energy consumption and economic evaluation of the alternatives that the user wants to compare by utilizing the decision support system of the Building Energy Integrated Support System. In general, the purpose is to obtain information on which alternative has the lowest energy requirement based on the performance evaluation results.

On the other hand, the need for an economic evaluation of the performance elements of the energy efficiency measures for buildings has been confirmed, and the methodology for supporting the comprehensive decision-making process through an economic evaluation is required. In addition, for each energy efficiency alternative, this study intends to support the user's decision-making by providing information through scoring analysis according to energy performance index of the energy-saving design criteria for domestic buildings.

Therefore, this paper proposes a decision support methodology for energy efficiency measures for buildings and derives the desired alternatives using the methodology based on the performance evaluation of the target building. The methodology and optimal package are composed of the primary energy consumption, LCC cost, and energy performance index; the process is presented in Figure 5.

First, alternative measures that meet the regulatory criteria for the target building that the user wants to evaluate are derived, and the energy consumption, economic efficiency, and energy performance index items for each alternative are evaluated. Among the evaluation results, the result conditions that the user wants to analyze preferentially are selected to make decisions on the building energy efficiency alternatives based on the result conditions. When the number of alternatives for the conditions is two or more, the conditions for deriving the optimal one out of the alternatives are selected. If there are two or more alternatives at this time, an alternative is derived by comparison in terms of the last condition. The optimal alternative is derived by conducting an analysis in a stepwise manner based on the result conditions that the user wants to analyze preferentially. Tables 7, 8, and 9 list the selected alternative by the preferred criteria in accordance with the proposed process.

5. Conclusion

This study proposed energy efficient alternatives (ECM List) by building a database of general-purpose values and price information based on the alternative method that can be applied and evaluated as a national public program, and the energy performance and economic efficiency of each alternative after setting a target building were evaluated. In addition, a decision support process was suggested and applied based on the evaluation results, and the building

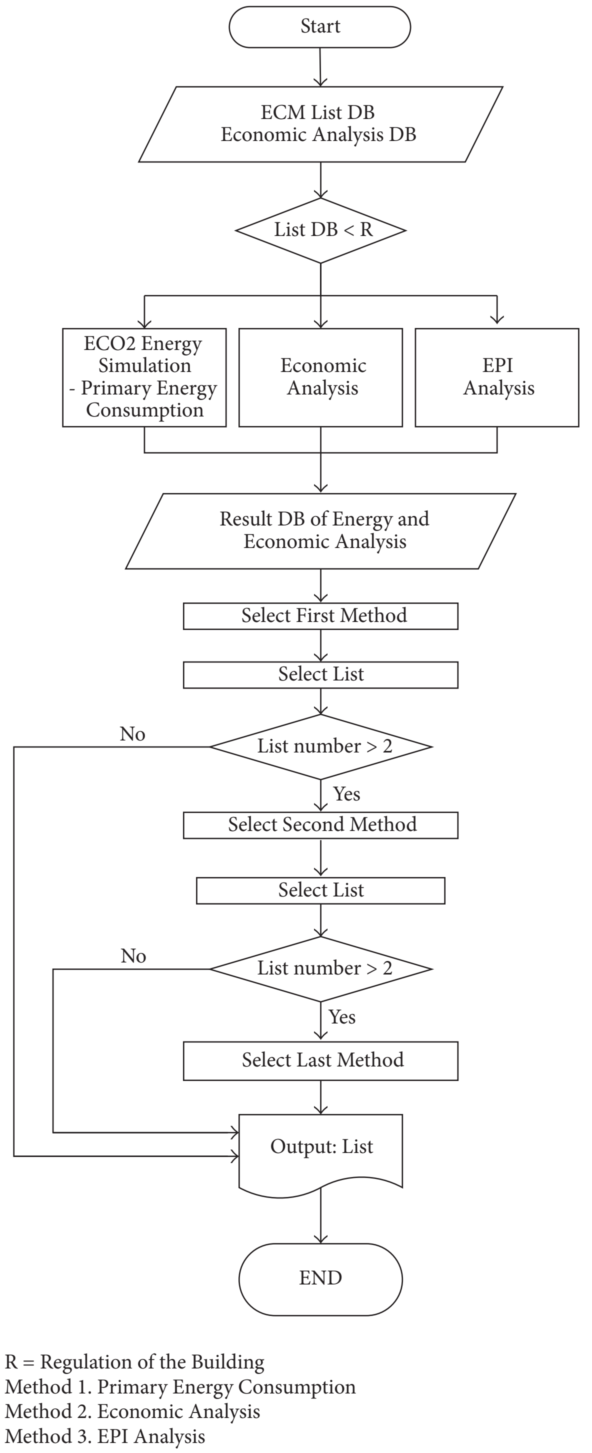

Figure 5: Building Energy Efficiency Decision Support process.

energy efficiency alternatives (Passive ECM List) for the target building were evaluated.

The results of this study can be summarized as follows:

(1) The energy efficiency alternatives about windows were divided into the window-to-wall ratios, U-values, and g-values for windows. Within the range satisfying the legal criteria for the target building, the window-to-wall ratios were determined to be 25%, 27%, 35%, 40%, 45%, 50%, and 55%. Regarding the windows, 12 kinds were derived according to the legal standards for U-values.

(2) With respect to the Passive ECM List for the target building, the primary energy consumption was evaluated by utilizing the ECO2. The energy-saving effect depending on the increase in the window-to-wall ratio compared to the original plan was not found. The evaluation results of the energy performance according to the U-values showed some ranges, so an economic evaluation is needed.

(3) For the costs of materials, labor, and energy consumption of the windows of the ECM List, the cost per unit area was calculated, and an alternative with the lowest LCC was derived among the alternatives for representing the same U-value and primary energy consumption.

Table 7: Selected alternative when considering the primary energy consumption preferentially.

Category	Primary energy consumption [kWh/m^{2}yr]	LCC [won/m^2]	EPI
Origin	357.7	1,754,851	0.8
Proposed	357.3	1,746,771	0.8

Table 8: Selected alternative when considering the LCC preferentially.

Category	LCC [won/m^2]	Primary energy consumption [kWh/m^{2}yr]	EPI
Origin	1,754,851	357.7	0.8
Proposed	1,746,771	357.3	0.8

Table 9: Selected alternative when considering the EPI preferentially.

Category	EPI	Primary energy consumption [kWh/m^{2}yr]	LCC [won/m^2]
Origin	0.8	357.7	1,754,851
Proposed	0.9	352.1	1,891,688

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

This research was supported by a grant from Technology Advancement Research Program (TARP) funded by Ministry of Land, Infrastructure and Transport of Korean government (16CTAP-C115251-01).

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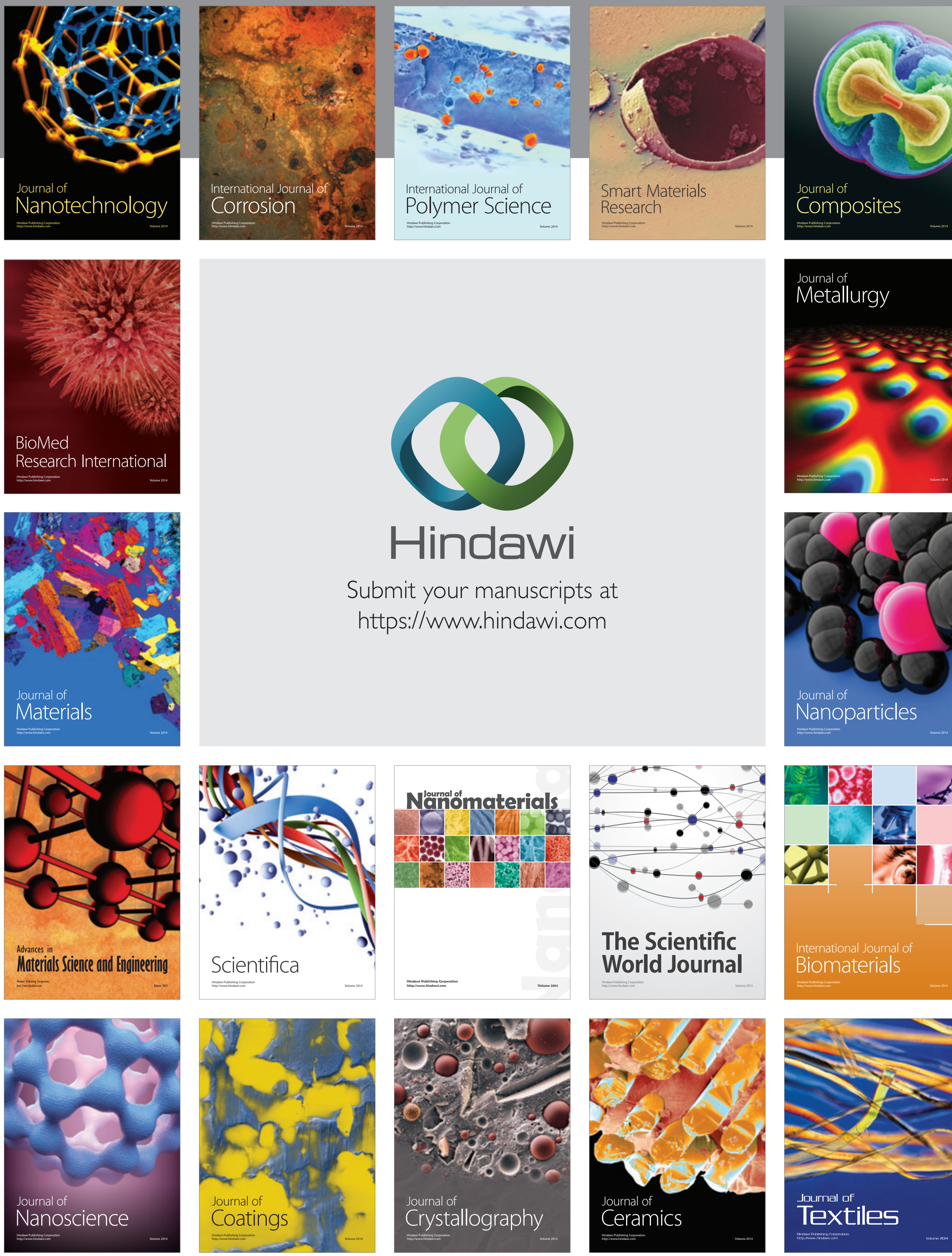

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