Hindawi
Advances in Civil Engineering
Volume 2018, Article ID 9102391, 8 pages
https://doi.org/10.1155/2018/9102391

Research Article

Energy Performance Evaluation and Economic Analysis of Insulation Materials of Office Building in Korea

Bo-Eun Choi,[1] Ji-Hyun Shin,[2] Jin-Hyun Lee ,[2] Hyo-Jun Kim,[2] Sun-Sook Kim,[3] and Young-Hum Cho [4]

[1]*Green Architecture Center, Korea Institute of Building Energy Technology, Seoul, Republic of Korea*
[2]*Department of Architectural Engineering, Graduate School of Yeungnam University, Gyeongsan, Republic of Korea*
[3]*Department of Architecture, Ajou University, Suwon, Gyeonggi, Republic of Korea*
[4]*School of Architecture, Yeungnam University, Gyeongsan, Republic of Korea*

Correspondence should be addressed to Young-Hum Cho; yhcho@ynu.ac.kr

Received 8 February 2018; Accepted 21 March 2018; Published 22 April 2018

Academic Editor: Geun Y. Yun

Building energy conservation measure (ECM) of insulation materials suitable for the domestic situation in the construction sector (passive) is established. The ECMs of insulation materials were classified into walls, roofs, and floors. Also, economic evaluation databases, which are composed of material costs, labor costs, and expenses for constructed alternatives, were built. After setting the target building and deriving the ECM list of insulation materials for the target building, the energy use evaluation and economic evaluation were performed for each constructed alternative. Based on this, the optimal building energy conservation measure of the target building was derived by applying the decision-support process.

1. Introduction

In the building sector in Korea, various efforts are being made to save energy, such as enacting and announcing the support system for the composition of green architectures and building design criteria for energy saving as well as energy conservation and efficiency management, including a performance evaluation system of eco-friendly homes, which are being carried out for new and existing buildings from the building design to the building operation. One of them is a web portal that provides information on green buildings. The purpose of this site was to provide a building energy integration support services, including energy use measurement of buildings and Energy Efficient Alternative Support system and so on.

The building design criteria for energy saving aims to determine the items related to the energy-saving design criteria, including heat loss prevention, writing standards of energy conservation plans and the design of review reports, and the relaxation of construction standards for promoting the construction of green buildings and for efficient energy management of buildings in accordance with the support system for composition of green architectures. It will be mandatory to submit an energy conservation plan at the time of the application for permission for construction or a use change in the case of buildings with a gross floor area of 500 m^2 or more. The review report of the energy conservation plan design is composed of mandatory items and recommendations. The adoption of all the 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 EPI for public buildings is prescribed as the requirements for a suitability determination. In addition, in the case of business buildings with a gross floor area of 3,000 m^2 or more, a report of a building energy use evaluation by the ECO2-OD must be submitted. ECO2-OD is a building energy requirement assessment program based on the international standard calculation technique ISO 13790 which is used to evaluate the energy performance of new and existing domestic buildings [1, 2].

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

$$\mathrm{LCC} = \mathrm{IC} + \mathrm{OCpv} + \mathrm{DCpv} = \sum_{t=0}^{n} \frac{C_t}{(1+d)^t}, \quad (1)$$

$$R = (1+r)(1+\mathrm{inf}) - 1, \quad (2)$$

$$r = \frac{(1+r)}{(1+\mathrm{inf})} - 1, \quad (3)$$

where IC is the initial investment cost, OCpv is the present value of the total operating cost, DCpv is the present value of the dismantling and demolition cost, d is the real discount rate, and C_t is all the costs incurred in the year t. In addition, R is the nominal interest rate, r is the real interest rate, and inf is the inflation rate.

According to the existing studies, Kim [3] remodeled the insulation for a study of an economic evaluation to carry out insulation work to conform to the strengthening legal insulation standards. Yeom [4] examined the economic feasibility of sustainable technologies using LCC analysis, in which the energy cost and CO_2 emission trading cost are considered. In this study, it is expected that the result can be used as a decision making tool for selecting sustainable building technologies during the initial building design stage. In the residential sector, the air conditioning system comprises the largest portion of the overall energy use to fulfil the thermal comfort needs. Aditya et al. [5] analyzed the recent developments on the building thermal insulation and discussed the life-cycle analysis and potential emission reduction using proper insulation materials to address the issue. Favoino et al. [6] designed and controlled an optimizing adaptive insulation for office buildings by minimizing the total primary energy use and thermal discomfort. The present study applied this framework to explore the potential of adaptive insulation. Choi et al. [7] developed energy conservation measures (ECMs) as a basic study for targeted methodologies and decision-support system development in Korea to meet the national regulations. Choi et al. [8] proposed a decision-making support process based on the performance evaluation results of building energy conservation measures. In addition, this study set up the target buildings, and the optimal ECM of insulation material for the target building was suggested through the application of a decision-making process. Various studies about energy performance evaluation and economic analysis have been carried out. However, there is a lack of study on the insulation of nonresidential buildings.

The purpose of this study was to develop the building energy conservation measure (ECM) and economic database of insulation materials suitable for a domestic situation. To apply the ECM of insulation materials, set the target building and conduct an energy use evaluation using the amended standard building energy rating system (ECO2), which is a national public program. In addition, this study conducted economic evaluation for each alternative using economic evaluation database based on actual materials and derived the optimal building energy conservation measures for the target building by applying the decision-support process.

2. Development of ECM List and Economic Evaluation Database of Insulation Materials

2.1. Development of ECM List. ECO2, which is used for the evaluating energy efficiency rating of domestic buildings, was developed in accordance with the German standard DIN V 18599, EN ISO 13790, and EN 15203, and it is a program for analyzing the energy required to maintain the indoor environment of a building suitable for the use of that building. This program quantitatively analyzes the energy required for heating, cooling, lighting, hot water, and ventilation considering the interaction of energy flow depending on characteristics of the building construction and equipment, and the calculated energy can be used to predict the building's primary energy demand, energy use, and carbon dioxide emissions.

To establish building energy conservation measures (ECMs) of insulation materials for the domestic situation, the input items of ECO2 are examined. The walls, roofs, and floors are divided into those that are exposed to the outdoor air directly and those that are exposed to the outdoor air indirectly according to the composition of the materials of the envelope structure in ECO2. The thickness of them is selected or entered directly to apply and evaluate them. This study sets the range (variables) of energy conservation measures concerning the U values of the walls, roofs, and floors after selecting only those for which the price information, including the specification (general-purpose thickness) and prices, can be built among the basic options of insulation materials in ECO2. Table 1 lists the basic options of insulation materials in ECO2. The type and thickness of the insulation material that constructed the price information from among the kinds of insulation materials that can be selected by default are listed. For the basic options of insulation materials in ECO2, there are 40 kinds available. Among them, 25 kinds of insulation materials for which the price information, including the specification and prices can be built, were selected, and 346 kinds were constructed as the energy conservation measures

Table 1: Types and thickness of the insulation materials.

Insulation materials	Thickness (mm)
Expanded polystyrene foam (EPS) type 1 number 1	10/25/35/50/55/65/70/75/80/90/100/105/125/140/155/190
Expanded polystyrene foam (EPS) type 1 number 2	10/25/35/50/55/65/70/75/80/90/100/105/125/140/155/190
Expanded polystyrene foam (EPS) type 1 number 3	10/25/35/50/55/65/70/75/80/90/100/105/125/140/155/190
Expanded polystyrene foam (EPS) type 1 number 4	10/25/35/50/55/65/70/75/80/90/100/105/125/140/155/190
Expanded polystyrene foam (EPS) type 2 number 1	10/20/45/50/60/70/75/85/90/120/140/160/180
Expanded polystyrene foam (EPS) type 2 number 2	10/20/45/50/60/70/75/85/90/120/140/160/180
Expanded polystyrene foam (EPS) type 2 number 3	10/20/45/50/60/70/75/85/90/120/140/160/180
Expanded polystyrene foam (EPS) type 2 number 4	10/20/45/50/60/70/75/85/90/120/140/160/180
Extruded polystyrene foam (XPS) special	10/20/30/. . ./110 (space 10)
Extruded polystyrene foam (XPS) number 1	10/20/30/. . ./110 (space 10)
Extruded polystyrene foam (XPS) number 2	10/20/30/. . ./110 (space 10)
Extruded polystyrene foam (XPS) number 3	10/20/30/. . ./110 (space 10)
Rigid polyurethane foam type 1, number 2	20/25/30/35/. . ./200 (space 5)
Rigid polyurethane foam type 1, number 3	20/25/30/35/. . ./200 (space 5)
Rigid polyurethane foam type 2, number 1	20/25/30/35/. . ./200 (space 5)
Rigid polyurethane foam type 2, number 2	20/25/30/35/. . ./200 (space 5)
Mineral wool number 1	25/50/75/100
Mineral wool number 2	25/50/75/100
Mineral wool number 3	25/50/75/100
Glass wool 24 K	25/50/75
Glass wool 32 K	25/50/75
Glass wool 40 K	25/50/75
Glass wool 48 K–120 K	25/50/75
Mineral wool blanket number 1a	25/50/75/100
Mineral wool blanket number 1b	25/50/75/100

Table 2: Method for calculating the investment cost DB for economic analysis.

Labor cost		Expenses						
Direct labor cost		Other expenses		Worker's compensation insurance	Health pension insurance	Long-term care insurance	Environmental preservation cost	Retirement cost deductible installment
Direct labor cost × rate		(Material cost + labor cost) × rate		Labor cost × rate	Direct labor cost × rate	Health insurance × rate	(Material cost + direct labor cost + expenses) × rate	Direct labor cost × rate
Construction	Industrial facility	Construction	Industrial facility					
7.6	7.6	6.4	6.4	Worker's compensation insurance: 3.8; employment insurance: 1.01	Health: 1.7; pension: 2.49	6.44	0.8	2.3

of the passive ECM list for the U value of the structure according to the thickness of each insulation material.

2.2. Development of Economic Evaluation Database. In the process of applying energy conservation measures to improve the energy saving and performance of existing buildings, an economic evaluation is essential to make a systematic and rational choice from the alternatives. In Korea, economic evaluation techniques for these alternatives are not standardized, so it is difficult to show the economics related to energy conservation as an accurate and consistent index. For this reason, a DB needs to be constructed for an economic evaluation of the energy conservation of buildings in an accurate and reasonable manner.

The database for economic evaluation of energy conservation measures for buildings is composed of investment costs and operating costs. The investment costs consist of material costs, labor costs, and expenses. The labor cost is divided into direct and indirect labor costs; the direct labor costs are calculated by reference to the "standard market unit price" of Public Procurement Service, and the indirect labor costs are calculated by reference to "the criteria for application of expense ratios in construction cost calculation." The expenses are the costs incurred by consuming the cost items other than material and labor costs; Table 2 lists the constituent elements of investment costs which are calculated by reference to "the criteria for the application of expense ratios in the construction cost calculation."

The operating costs composed of the following: maintenance expenses and energy costs. Maintenance expenses are the total cost of the repair cost and replacement cost. The repair and replacement costs can be estimated through the repair (replacement) cycle and repair (replacement) rate.

Table 3: Repair and replacement costs of insulation.

Construction type	Repair method	Maintenance cycle (year)	Rate of repairing level (%)	Note
Adiabatic layer (wall, ceiling)	Repair parts	15	20	A protective layer (except cavity wall insulation layer)
	Full repair	50	100	

Table 3 presents the maintenance cycle and rate of repairing level of insulation which is a part of the criteria for long-term repair plan establishment in the Housing Act Enforcement Regulations (effective 01/07/2015).

The energy costs consisted of electricity charges, city gas, and district heating. The electricity charges are based on the rates provided by KEPCO (Korea Electric Power Corporation). The electricity charges for nonresidential buildings are divided into the following: for general use, for industrial use, and for educational use. The electric power rates depend on the contract power. The electricity charges are divided into those for the contract power of less than 300 kW and those for a contract power of 300 kW and more. The electricity costs are calculated using the following formula:

$$\text{Electricity charge} = (\text{Cbasic} + \text{UC} - \text{Dwelfare}) \times \text{VAT} \times \text{electric power industry basic fund}, \tag{4}$$

where Cbasic is the basic price, UC is the usage charge, and Dwelfare is the welfare discount. In addition, the VAT is 10%, and the electric power industry basic fund is 3.7%.

City gas charges vary according to the region, and the charges offered by local natural gas suppliers are applied and are divided depending on the types of use. The city gas charges are calculated using (5).

For district heating charges, the charges provided by the Korea District Heating Corporation are applied and are charged differently according to the contract types:

$$\text{City gas price} = (\text{used amount} \times \alpha) \times C \times \text{unit price} + \text{replacement cost} + \text{VAT}, \tag{5}$$

where α is the correction factor, C is the average calories which was used in calculating the city gas charges referring to the monthly weighted average calories of a specific period (MJ/Nm^3).

All costs for the economic evaluation in this study were calculated per unit area (m^2). The labor costs for the insulation work on the walls, roofs, and floors were based on the unit labor costs of the 2015 standard quantities per unit of construction work, as listed in Table 4. The classification in terms of the kinds of insulation materials was not conducted, and the labor costs according to the installation positions of polystyrene foam (Styrofoam) were calculated. Because the quantity per unit includes extra charges for materials and small transportable items, the expenses were not calculated separately and LCCs were calculated as the sum of the costs of materials and labor costs.

Table 4: Unit labor cost per unit area of the installation of insulating materials according to the parts of the structure.

Interior finishing worker	Wall	Roof	Floor
126.84 USD	0.0500 person 6.34 USD	0.0600 person 7.61 USD	0.0120 person 1.52 USD

Table 5: Overview of the target building.

Category		Description
Building information	Region	Gyeonggi
	Use	Public building
	Structure	Reinforced concrete
	Size	1 floor underground, 3 floors above ground
	Gross floor area	2,325 m^2
Mechanical system	Cooling/heating	Absorption chiller-heater, boiler, EHP
	HVAC	HVAC, FCU
	Renewable	Geothermal heat pump

3. Derivation of Optimal Energy Conservation Measures

3.1. Overview of the Target Building. In this study, a public building was set as the target building to derive and evaluate the passive ECM of insulation materials. The selected building was a 3 story nonresidential business building with a gross floor area of 2,325 m^2. Tables 5 and 6 present an overview of the target building and the information on the envelope performance of building, respectively. Table 7 lists the analysis results of the annual primary energy use per unit area of the target building by utilizing ECO2.

3.2. ECM List for the Target Building. Because the walls of the target building are exposed to the outdoor air directly, the U value of 0.270 W/m^2·K or less for the external walls of the living room in the central region must be satisfied. Therefore, when 346 kinds of constructed alternatives were applied to the walls of the target building, 136 alternatives that met the regulatory criteria were derived. The floors of the target building consisted of those exposed to the outside air directly and those exposed to the outside air indirectly, but only those exposed to the outside air indirectly were considered because the floors exposed to the outside air directly (the pilotti of the main entrance part on the first floor) were very small. The living room on the lowest floor of the target building must meet the criterion of 0.410 W/m^2·K or less, and when the constructed alternatives are applied to the floors of the target building, 233 kinds satisfying the regulatory criteria were derived. In addition, because the roof of the top floor of the target building is exposed to the outdoor air directly, it must meet the criterion of 0.180 W/m^2·K or less. When the constructed alternatives were applied to the

Table 6: Envelope performance of the target building.

Building component	U value (W/m^2·K)	Legal criteria (W/m^2·K)	Building component	U value (W/m^2·K)	Legal criteria (W/m^2·K)
Wall (direct)	0.244	0.270	Window (direct)	2.0	2.100
Roof (direct)	0.165	0.180	Window (direct)	1.9	2.100
Floor (direct)	0.254	0.290	Window (indirect)	2.4	2.600
Floor (indirect)	0.237	0.410	Door (direct)	1.8	2.600
—	—	—	Door (indirect)	2.3	2.100

Table 7: Results of the primary energy use (kWh/m^2·yr) for the target building.

New and renewable energy	Heating	Cooling	Hot water	Lighting	Ventilation	Total
0.0	111.9	91.5	27.4	62.2	64.7	357.7

roof of the target building, 64 of them met the regulatory criterion.

3.3. Energy Use Evaluation of ECM. For the alternatives of the ECM list for the target building derived in Section 3.2, the primary energy use was evaluated using the building energy efficiency rating program (ECO2). In the domestic building energy efficiency rating, energy use for cooling is not assessed or considered in the case of residential buildings, but for nonresidential buildings, the total energy use according to each load is considered, so the total energy use including energy use for cooling and heating was analyzed in this study.

3.3.1. U Values of the Walls. In this study, there are 136 kinds of alternatives for the walls that meet the regulatory criterion of 0.270 W/m^2·K or less for the walls exposed to the outdoor air directly, including the original plan; Figure 1 presents the total primary energy use according to the type and thickness of the insulation material. The total primary energy use ranged from 355.5 to 358.0 kWh/m^2·yr, and several ranges where the same energy use results were found with different U values were identified.

3.3.2. U Values of Roofs and Floors. The alternatives for the roof that meet the regulatory criterion of 0.180 W/m^2·K or less for the roofs, which are exposed to the outdoor air directly, are 64 kinds including the original plan of the target building; Figure 2 shows the primary energy use according to the type and thickness of insulation materials. The total primary energy use ranged from 357.1 kWh/m^2·yr to 358.0 kWh/m^2·yr, and several ranges, where the same energy use results were observed with different U values, were identified, as in the case of the U values for walls. The alternatives for the floors of the target building that meet the regulatory criterion of 0.410 W/m^2·K or less for the floors exposed to the outdoor air indirectly were 233 kinds, including the original plan of the target building. Figure 3 presents the primary energy use according to the type and thickness of insulation materials; the total primary energy use ranged from 357.0 kWh/m^2·yr to 358.6 kWh/m^2·yr. In several ranges, the energy use results were identical, even though the U values were different, as in the case of the U values of the walls and roofs.

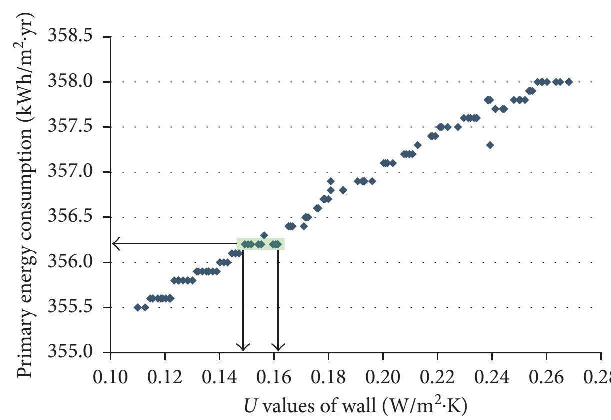


Figure 1: Primary energy use according to the U values for the walls of the target building.

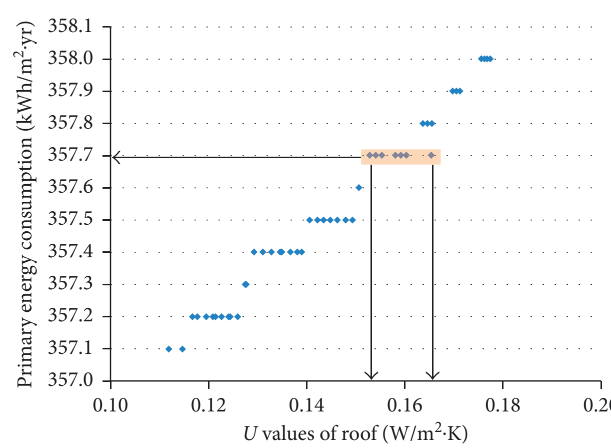


Figure 2: Primary energy use according to the U values for the roofs of the target building.

To derive the energy-efficient alternatives concerning the U values of the walls, roofs, and floors using an integrated support system that supports the user's decision making, it is necessary to derive the most efficient alternative through price information.

3.4. Economic Evaluation of ECM. Figure 4 shows the LCCs according to the U values of the walls among the energy

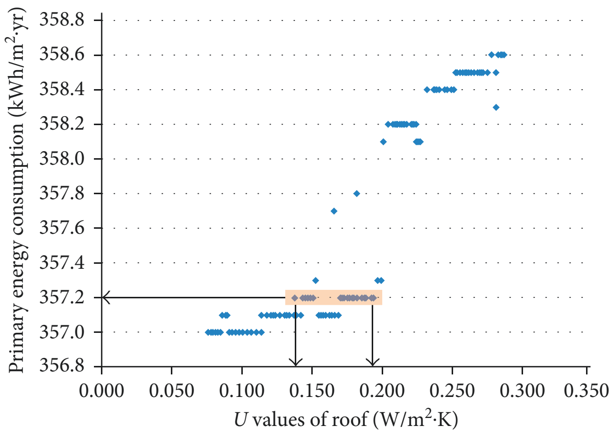


Figure 3: Primary energy use according to the U values for the floors of the target building.

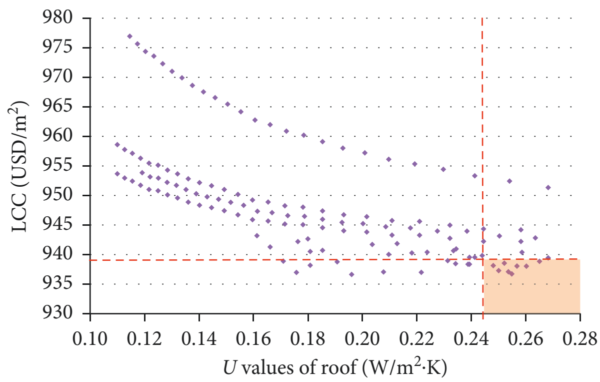


Figure 4: LCC according to the U values of the walls.

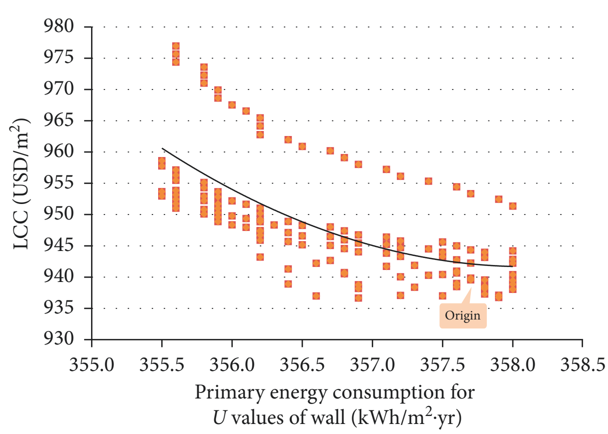


Figure 5: LCC according to the primary energy use for the U values of walls.

efficient alternatives for the target building. The costs decreased with increasing U value, but there were large differences in the cost with the same U values. Figure 5 shows the LCCs depending on the primary energy use. The graph of the costs according to the U values of the walls shows that the impact of the LCCs was greater than that of the energy costs depending on the energy use. The existing wall insulation

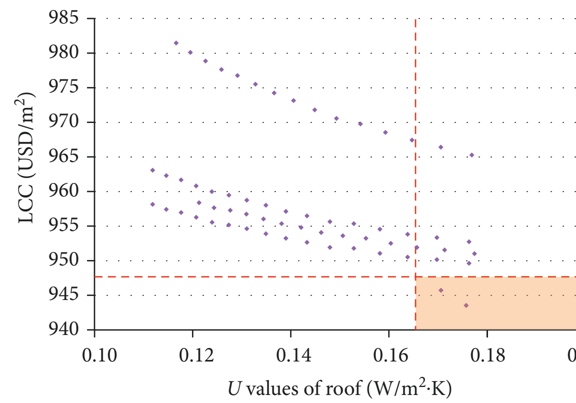


Figure 6: LCC according to the U values of the roofs.

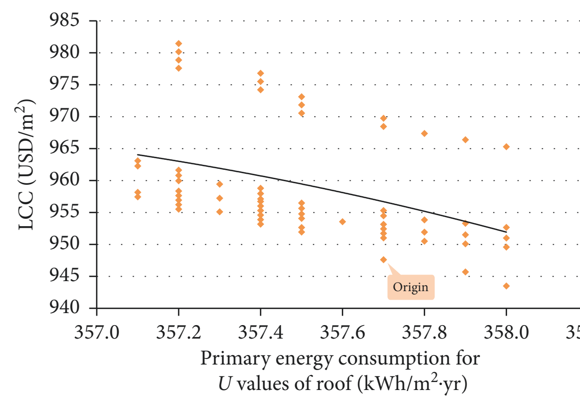


Figure 7: LCC according to the primary energy use for the U values of the roofs.

materials (original plan) of the target building showed the lowest LCC among the insulation materials that represent the same primary energy use, but the alternative that represents lower energy use with the same LCC was derived.

Figure 6 presents the LCCs depending on the U value for the roof of the target building. Although the costs generally decreased with increasing U value, there were large differences in the costs with the same U values. Figure 7 presents the LCCs depending on the primary energy use. The existing insulation material of the target building (the original plan) shows the lowest LCC among the insulation materials, which represent the same primary energy use. Unlike the case of walls, the alternative that represents less primary energy use with the same LCC was not derived, so the original plan was considered to be cost-effective.

Figure 8 shows the LCCs of the target building according to the U values for floors. Although the cost generally decreases with increasing U value for the floor, as in the case of walls and roofs, there were considerable differences in the costs with the same U values. In addition, the floor is the item with the greatest number of alternatives that meet the regulatory criteria among the different structures of the outer wall, and more alternatives that represent the same energy costs (energy use) were derived than in the case of the walls or roof. Figure 9 shows the LCCs for the primary

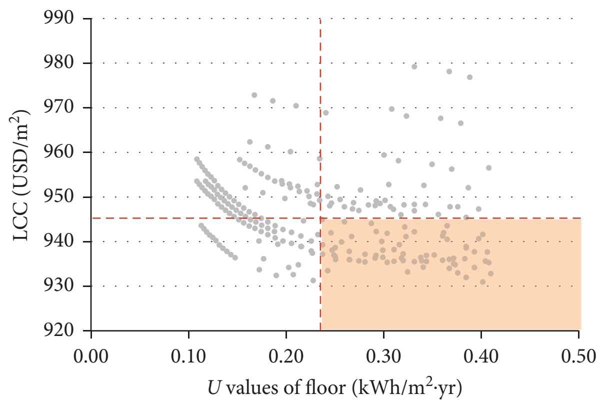


Figure 8: LCC according to the U values of the floors.

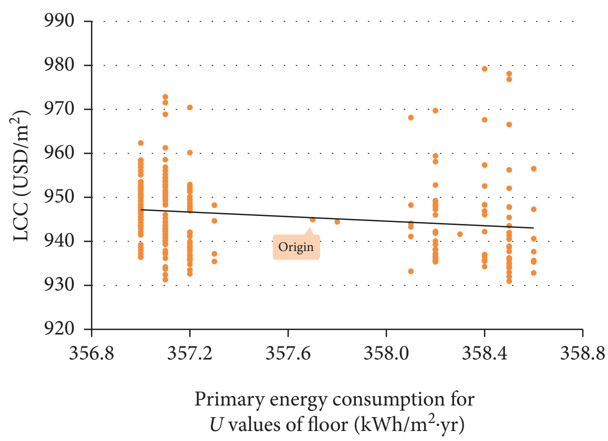
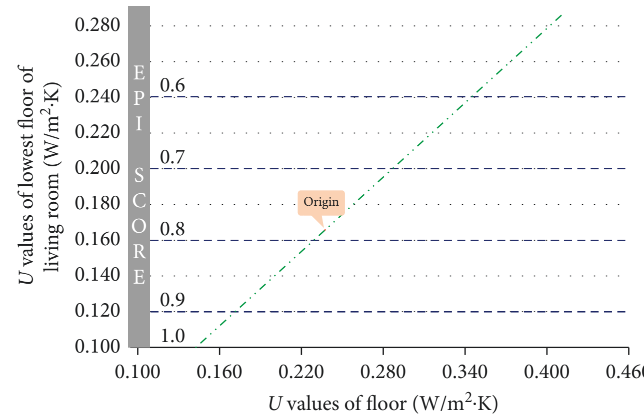
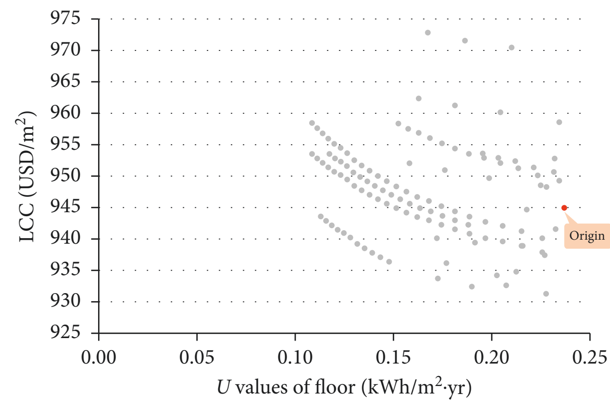


Figure 9: LCC according to the primary energy use for the U values of the floors.



(a)



(b)

Figure 10: Deriving optimal energy conservation measures of the target building: (a) U value of floor's alternative derivation according to the U values of floor; (b) U value of floor's alternative derivation according to the LCC.

energy use. The alternatives representing less primary energy use with the same LCC were derived, as in the case of the walls.

3.5. Optimal Energy Conservation Measures. Many conditions can allow the users to make decisions using the decision-support system of buildings. In general, the energy use will be taken as a priority, and the purpose is to obtain information regarding which alternative has the lowest energy use based on the performance evaluation results. On the other hand, the necessity of an economic evaluation has been confirmed when selecting energy conservation measures, and a methodology to support comprehensive decision making through economic analysis is needed. Therefore, through the decision-support process presented in Choi's studies, which considers the energy requirements, economic evaluation, and EPI points, this study derives optimal energy conservation measures of the target building [7, 8]. Figure 10 shows the derivation of energy conservation measures focusing on the U value of floors. It is possible to know the U value of the floors which can increase the EPI scores of the U value of the lowest floor of the living room and the lowest LCC. Based on this, optimal energy conservation measures of the target building can be derived.

4. Conclusion

This study proposed energy conservation measure (ECM) list by building a database of general-purpose values and price information based on the measures that can be applied and evaluated as a national public program and evaluated the energy performance and economic of each alternative after setting a target building. In addition, the optimal building passive ECM list for the target building was evaluated by applying the decision-support process.

The results of this research can be summarized as follows:

(1) The energy conservation measures of the passive ECM list were divided into the U values of walls, roofs, and floors. Within the range satisfying the legal criteria for the target building, there were 346 kinds of alternatives concerning the U values of walls, floors, and roofs in total. Among them, 136 types were derived for the alternatives meeting the

legal criteria for the walls of the target building, 133 kinds were derived for the floors, and 64 kinds were derived for the roofs.

(2) With respect to the passive ECM list of the insulation material for the target building, the primary energy use was evaluated using ECO2. The evaluation results of the energy performance according to the *U* values of the walls, floors, and roofs of the target building showed many ranges, where the same energy use was observed with different *U* values, so the necessity for an economic evaluation for the performances of the ECM list was confirmed.

(3) For the materials, labor, and energy use costs of the performance factors of the passive ECM list, the cost per unit area was calculated, and an alternative with the lowest LCC was derived among the alternatives representing the same *U* value and primary energy use. For the walls, because it represents the lowest LCC compared to the alternatives with the same energy use as the original plan, it is considered to be cost-effective, but the alternative that allows the LCC to be recovered within three years through energy savings was derived. For the roof and floors, because it represents the least LCC among the *U* values that represent the same primary energy use, it is considered to be cost-effective, but the alternative that allows the LCC to be recovered through energy savings was not derived. Therefore, it was considered efficient to maintain the original plan.

(4) By applying the decision-support process, the energy conservation measures for the target building were derived, and the utility of the integrated analysis method for deriving the energy conservation measures was confirmed through examples.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

All authors contributed to this work. Bo-Eun Choi built ECM and economic DB and wrote the major part of this article. Ji-Hyun Shin and Jin-Hyun Lee built ECM and economic DB. Hyo-Jun Kim conducted the energy simulation. Sun-Sook Kim performed the result discussion and gave technical support. Young-Hum Cho was responsible for this article and gave the conceptual advice.

Acknowledgments

This research was supported by a grant (18AUDP-B079104-05) from Architecture and Urban Development Research Program funded by the Ministry of Land, Infrastructure and Transport of Korean government.

References

[1] Ministry of Land, Infrastructure and Transport, *Energy Saving Plan*, Ministry of Land, Infrastructure and Transport, Sejong, Korea, 2015.

[2] ISO 13790, *Energy Performance of Buildings–Calculation of Energy Use for Space Heating and Cooling*, ISO, Geneva, Switzerland, 2008.

[3] S. Kim, "A study on the economic evaluation of thermal insulation remodeling," *Journal of the Korean Institute of Building Construction*, vol. 15, no. 1, pp. 142-143, 2015.

[4] Y. Yeom, "A study on economic feasibility evaluation method of sustainable building technologies using life cycle cost analysis," *Proceedings of the Architectural Institute of Korea*, vol. 28, no. 1, pp. 655–658, 2008.

[5] L. Aditya, T. M. I. Mahlia, B. Rismanchi et al., "A review on insulation materials for energy conservation in buildings," *Renewable and Sustainable Energy Review*, vol. 73, pp. 1352–1365, 2017.

[6] F. Favoino, Q. Jin, and M. Overend, "Design and control optimisation of adaptive insulation systems for office buildings. Part 1: adaptive technologies and simulation framework," *Energy*, vol. 127, pp. 301–309, 2017.

[7] B.-E. Choi, J.-H. Shin, J.-H. Lee, S.-S. Kim, and Y.-H. Cho, "Establishment of passive energy conservation measure and economic evaluation of fenestration system in nonresidential building of Korea," *International Journal of Polymer Science*, vol. 2017, Article ID 8681737, 9 pages, 2017.

[8] B.-E. Choi, J.-H. Shin, J.-H. Lee, S.-S. Kim, and Y.-H. Cho, "Development of decision support process for building energy conservation measures and economic analysis," *Energies*, vol. 10, no. 3, p. 324, 2017.