Article

The Economic Feasibility of Passive Houses in Korea

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Abstract: The number of passive houses and zero-energy buildings being developed is increasing, as measures to reduce the rapidly increasing building energy consumption. While government building policies focus on energy savings, investors and the building market emphasize the initial investment cost. These conflicting perspectives obstruct the development of passive houses in the building market. In this study, a series of building energy analyses, including the effect of energy saving measures and economic information considering long-term economic benefit and incentives policy, will be presented. Analyses were performed on the energy-saving measures needed to improve the performance of single-family houses in Korea to that of the passive house standard, as well as the energy saving effect and increased cost. The application of energy saving measures for passive house implementation resulted in an additional cost of 1.85–4.20% compared to the conventional reference house. In addition, the proposed passive house alternative shows a short payback period and life cycle cost (LCC) result, compared to a conventional building's life cycle period. The possibility of passive house implementation is high, and developing the passive house is affordable for the investor or end user in Korea.

Keywords: passive house; energy-saving measures; energy performance analysis; economic analysis

1. Introduction

The building sector accounts for more than one-third of the total global energy consumption, and the projected increase in total energy use will be increased more than two-fold in the near future. Consequently, global building energy consumption could increase by 50% by 2050 [1]. Most countries have national policies and regulations to reduce building energy consumption and promote the passive house in the building market. The term passive house generally refers to a type of low-energy house [2,3]. Recently, the subdivided criteria of passive house are suggested according to the reducible energy demand by applying renewable energy sources and improved appliances [4]. Among the various definitions of the passive house, the most widely known concept of passive house is the 1.5 L house. It means that the heating energy requirement of the passive house should be less than 15 kWh/m²·year, with a heating load of less than 10 W/m² [5]. The concept of the passive house has been adopted by more than 40 countries and institutions, and it is the basis of the building energy policies in the world [6–9]. Moreover, the physical performance criteria of the zero-energy building, a building with zero net energy consumption, is proposed as an intensified building energy-saving measures based on the physical standards of the passive house [10]. Therefore, the implementation of the passive house is a key issue in achieving the international goal of reducing carbon emissions in the building sector.

In order to reduce building energy at the national level, general action plans in the building market for passive house implementation have been devised. The aims of these action plans are as follows: (1) to strengthen the performance of the building envelope [11–15], (2) to apply energy-efficient HVAC systems [16–20], and (3) to apply renewable energy systems [21–24]. With the efforts and policies for building energy saving at the national level and active global discussions on energy issues, the interest by builders and investors in the passive house has also increased in the building market. However, the construction status of the world's passive house construction by year [25] is static despite an increase in policy and social interest; i.e., investors have major barriers to overcome when investing in passive house projects.

Previous studies [26–31] revealed that the reason why the spread of passive houses in the building market is so slow is that the passive house [32], although suggested as having only a “slightly higher investment cost”, actually involves excessive investment costs, which is a major barrier [33]. Zhang et al. [29] mentioned that the implementation of green elements for property development projects involves various barriers that are absent in conventional buildings, such as the higher cost of green appliance design and energy-saving materials, lengthy planning and approval process for new green technologies and recycled materials, and the lack of familiarity with green technologies, resulting in delays in the design and construction process. Overall, the high additional cost is considered to be the strongest barrier for applying green technologies in China. With similar results, Osmani et al. [31] carried out a questionnaire survey and in-depth semi-structured interviews with the major UK housing developers, with results showing that the lack of data relating to the cost of zero carbon homes and a shortage of financial incentives were recognized by 78% and 71% of the survey participants, respectively, as being significant or major barriers to delivering zero carbon homes in England.

In most countries, an incentive policy is established to encourage the participation of investors in implementing passive houses [8]. Despite the energy-saving advantages of building a passive house, high investment costs, ambiguous investment cost information, and limited incentive policies result in deterring investor participation in passive house projects.

The main goal of the building energy policy in many countries is the reduction of building energy. Therefore, most newly constructed buildings are designed to satisfy only the energy performance of the building as required by the building code [34]. In addition, the amount of available economic information, which plays an important role in the decision-making of the investor and end user, is inefficient [35]. In the market, investors and end users make economy-based decisions, and their role in green building activity is gradually increasing [36]. Therefore, providing reasonable investment cost and appropriate cost information is critical for increasing investor participation in the low-energy building market [37,38].

Actually, the initial investment cost of the passive house varies greatly depending on the region according to the energy consumption status, climatic conditions, and national financial environment [39]. Also, the initial investment cost of the passive house varies greatly even in the same area, depending on the energy reduction technologies proposed by the builder. Therefore, a valuation of an energy performance feature of the passive house or zero-energy building is needed to determine total cost occurred during whole life cycle period on building. The importance of including the energy certification of buildings in property valuation may, in turn, motivate an improvement in energy efficiency in housing and an improvement in the environment in general [40].

2. Building Energy State in South Korea

South Korea is the ninth largest energy consuming country in the world, accounting for 2% (6th) of the global CO₂ emissions [41]. The building sector accounts for about 26% of the total energy consumption [42] and half (50.6%) of the building energy consumed is used in residential building sectors in Korea [43]. The energy consumption rate of a residential building in Korea is very high [44], and its projected energy consumption rate is the fastest-increasing among the Asia-Pacific region [43].

The Korean government planned a national energy-saving roadmap aimed at achieving a passive house standard by 2017, and a zero-energy building standard to be introduced in 2025 [45].

An action plan called the Building Design Criteria for Energy Saving (BDCES) is a mandatory regulation for new construction of buildings in Korea. BDCES comprises sets of energy-saving design criteria as follows: 1 Construction Design Criteria (thermal insulation and heat resistance requirement for the building envelope); 2 Machinery design (indicators for calculating heating/cooling capacity design, district heating connections, and installed pump or fan performance); 3 Electric Facility (use of efficient transformers, motors, and lighting); and 4. Renewable Energy Facility Design (installation of renewable technologies) [46]. BDCES was first proposed in 2001 and is now mandatory for all types of buildings where high energy consumption is expected. The BCDES plan has been continuously strengthened for achieving the passive house and zero-energy building criteria, and the applications have been extended. The requirements for achieving a zero-energy building standard in Korea as follows [47];

- a. Prerequisite: Buildings that require zero-energy building certification must be buildings with an energy efficiency rating of 1++ or 1+++ (Table 1).
- b. Level: Zero-energy building (ZEB) level is divided into five levels according to the ratio of renewable (primary) energy rate for the required primary energy ($\text{kWh/m}^2\cdot\text{year}$), as shown in Table 2.

Table 1. Building Energy Efficiency Certification.

Level	Residential Buildings	Except Residential Buildings
	Required primary energy per unit area per year ($\text{kWh/m}^2\cdot\text{year}$)	
1+++	<60	<80
1++	60~90	80~140

Table 2. ZEB (Zero-Energy Building) Certification.

Level	Renewable (Primary) Energy Rate (%) = (Renewable Primary Energy Generation per Unit Area per Year ($\text{kWh/m}^2\cdot\text{year}$)/Required Primary Energy per Unit Area per Year ($\text{kWh/m}^2\cdot\text{year}$) $\times 100$
1	>100
2	80~100
3	60~80
4	40~60
5	20~40

Along with the BCDES, the Korean government is disseminating passive houses through obligation and incentive policies [48]. Despite the government policy and growing public interest in the green building market [49], the participation of end users in the Korean building market is low (Figure 1). The main reason is the limit of the building energy policy, which does not reflect the requirements of the Korean building market. The design criteria and energy-saving materials, as green technologies used to implement the passive house in the Korean building market, are not fully prepared at this point. This results in a strong dependency of foreign high-efficiency energy reduction technologies and results in high initial investment costs in implementing the passive house project in Korea [50]. Another obstacle to the dissemination of passive houses in the Korean housing market is the very short life span of Korean building. The average useful life of building is 26 years in Korea. Also, while long-term economic saving is generated by the reduction of building energy cost in a passive house, the high initial investment cost renders it difficult to ensure cost recovery during the building's life cycle in Korea [51,52].

Figure 1. Number of construction permits in Korea (2010~2016) [53]: PH residential* is a number of residential building using primary energy consumption less than 120 kWh/m²·year, PH non-residential** is a number of non-residential building using primary energy consumption less than 200 kWh/m²·year.

For this reason, developers tend to construct a building at the level that meets the regulatory performance, rather than at the passive house level. Also, compliance with the building energy performance regulation (BDCES) is only mandatory for buildings with a floor area of 500 m², or more, in Korea. Therefore, single or detached family houses, which consume a high level of energy and account for about 36 percent of all buildings in Korea [54], are not subject to BDCES. Since the sensitivity of initial investment cost is high in the Korean building market, it is very important for consumers to provide information on economic efficiency based on accurate energy analysis in passive house projects in Korea.

3. Research Method

The purpose of this study is to present the information required in the decision-making process for constructing a passive house from the viewpoint of the client. The analytical method determines the energy performance of various energy-saving measures for achieving a passive house and its economic benefits. By analyzing the building energy consumption at reference building, the proper energy-saving measures for achieving passive house standard will be suggested. Economic analysis is performed of the initial investment cost, long-term energy cost saving effect, and incentive.

3.1. Energy Performance Analysis

Analysis was carried out on the energy-saving effect of various measures to improve the performance of the single family house to reach that of the passive house in the Korean building market. The reference building to be analyzed is a single family (4 person) detached house, completed in 2014, and consists of one basement floor and two ground floors, located in Yangpyeong, Gyeonggi province, South Korea (Figure 2). The reference building faces south and has a total floor area of 177.98 m². The residential building in Korea should be satisfied building thermal performance criteria [47]. The thermal performance of the reference building is good compared to the existing residential building in Korea (Table 3). Initial investment costs were USD 194,161, excluding land costs.

The building energy performance analysis was conducted by EnergyPlus [55]. A typical weather data in Yangpyeong is used for analyzing with the building energy simulation. The input data for the simulation are shown in Table 3. The internal heat gain is based on the heat level data of the residential building provided by the Ministry of Land, Infrastructure, and Transport of Korea. The intensity and operating time of the lighting were sourced from the lighting intensity data of residential buildings provided by ASHRAE [56]. The infiltration rate of the reference building is based on a previous study [57] based on the measurement data of new-construction buildings in Korea. The ventilation system is not installed in the reference building, because ventilation system is not obligatory in single family or detached houses in Korea. The insulation performance of the reference building and the HVAC system were input data based on the design and construction data of the reference building.

Figure 2. Photo of the reference building.

Table 3. Simulation conditions of the reference building.

		Max/min	Average
Outdoor condition	Dry-bulb temp (°C)	35/−14.7	12.15
	Relative humidity (%)	100/11	68.98
	Wind speed (m/s)	6.4/0	1.22
	Solar irradiance (MJ/m ²)	3.03/0.03	0.55
Designed indoor thermal condition [58]		summer	winter
	Dry-bulb temp (°C)	26	20
	Relative humidity (%)	50	50
Internal heat gain [59]	Lighting (W/m ²): 5.5 [56]		
	Equipment (Wh/m ² ·day): 52		
	People (Wh/m ² ·day): 53		
Infiltration rate [57]	1.0 ACH at 50 Pa		
Ventilation system	uninstalled		

Table 3. Cont.

Building component	Material (mm)		Heat capacity [J/kg · K]	U-value [W/m ² K]
Exterior wall	Expanded polystyrene (50)		1210	0.160
	Oriented strand board (11)		1260	
	Glass wool (140)		960	
	Gypsum board (19)		1090	
Inner wall	Gypsum board (19)		1090	0.175
	Glass wool (140)		960	
	Gypsum board (19)		1090	
Ground floor	Strip flooring (8)		1630	0.171
	Plain concrete (64)		920	
	Extruded polystyrene (50)		1210	
	Concrete (300)		920	
	Extruded polystyrene (100)		1210	
	Blinding concrete (60)		920	
1st floor	Strip flooring (8)		1630	0.114
	Plain concrete (64)		920	
	Extruded polystyrene (50)		1210	
	Glass wool (235)		960	
	Gypsum board (19)		1090	
Roof	Oriented strand board (11)		1460	0.146
	Glass wool (235)		960	
	Gypsum board (19)		1090	
Window	Glass			2.71
	Frame			1.59
	Area (m ²)			36.65
	SHGC			0.47
HVAC System	Radiant floor heating with thermostat control, Gas-fired (Efficiency: 83%)			
Shape factor	0.698			

3.2. Economic Feasibility

Various energy-saving measures are applied to implement the passive house. In the long term, as the energy reduction rate increases, the economic feasibility increases, but the excessive initial cost increases, hindering the spread of passive house constructions. The decision-making process according to the appropriate financial level, between the economic advantage in the short term and that in the long term, is important in a building market centered on passive houses. Therefore, information on the economic feasibility features of the passive house should be provided for the end-user's decision making. This information includes the short-term investment-cost change and the long-term economic advantage due to the application of energy-saving measures for building passive houses.

A variety of building economics analysis methods have been proposed and applied [2,60,61]. In this study, economic analysis was used based on past economic fluctuation information, which has been used for 5 years [62] in the building industry, and can be easily understood by the end user [63]. The economic analysis method based on building energy-saving measures was carried out using a payback period analysis showing the result of the principal payback period and the life cycle cost (LCC) analysis showing the financial advantage generated during the building life cycle.

LCC analysis should consider the economic fluctuation per period, which consists of interest, energy inflation rate, and core producer price. Economic fluctuation information should be reflected, along with the appropriate price information. However, because it is difficult to predict the future economic fluctuation due to various influences, economic fluctuation data were based on historical

data. Table 4 shows the general conditions for analyzing economic feasibility of a passive house in Korea. The energy inflation rate is divided into electricity and natural gas. The interest value was set at 1.5%, reflecting the change in interest rates over the last five years in Korea [64], and the electricity inflation rate was similarly set at 3.3% [65]. The natural gas charge in Korea varies depending on the season, whereby the natural gas inflation rate increases in winter and decreases in summer. The natural gas inflation rate was 3.76% based on the average inflation rate over the past 5 years [66]. The core producer price measures the change in the selling price of goods and services sold by producers, and is used to reflect price fluctuation rate of products in the LCC analysis. The core producer price rate was estimated to be 1.5% based on the change in the origin price index of Korea in the last five years [67].

Table 4. Conditions for economic analysis.

Type	Interest	Electricity Inflation Rate	Natural Gas Inflation Rate	Core Producer Price
Rates	1.5% [64]	3.3% [65]	3.76% [66]	1.5% [67]

4. Energy Performance Analysis

4.1. Energy Consumption Status at the Reference Building

The energy consumption and peak heating loads of the reference buildings were analyzed to compare the passive house performance criteria [5]. The simulation results were compared with the actual heating energy consumption data of the reference building.

The annual heating energy consumption of the reference building is estimated at 41.25 kWh/m²·year. The average heating energy consumption of the reference building is reduced by 41% compared to the average heating energy demand of the residential building in Korea (98.50 kWh/m²·year). This is 2.75 times higher than the passive house standard (15 kWh/m²·year), as shown in Figure 3a. The peak heating load of the reference building is 38.95 W/m², which is 3.9 times higher than the passive house standard (10 W/m²). Although the thermal performance of the envelope in the reference building is superior to that in the existing residential building in Korea, it shows higher heating energy consumption and peak heating load than the passive house standard. About 45% of the peak heating load was caused by infiltration, as shown in Figure 3b.

Building energy models must be calibrated to closely represent the actual performance of modeled buildings. Calibration can significantly improve the validity of and confidence in energy models, while being used to compare the cost-effectiveness of energy conservation measures (ECMs) in the design stage. Building energy simulation models are considered “calibrated” if they meet the internationally accepted criteria defined by ASHRAE Guideline 14 [68,69]. The actual heating energy use of the reference building for 5 months (November to March) was measured to calibrate the building energy model in this study. The predicted heating energy demand and actual usage are shown in Figure 4. When the mean bias error (MBE) is within ±5%, and the coefficient of variance of root mean squared error (CVRMSE) is less than 15%, the simulated result is seen as reliable. The MBE between the measured value and the predicted value of the reference building is 3.1%, and the CVRMSE is 13.8%. The energy prediction results, based on the simulation in this study, are reliable.

Figure 3. Result of heating energy demand and peak heating load: (a) Result of heating energy demand; (b) Result of peak heating load.

Figure 4. Comparison of predicted and measured heating energy demand.

4.2. Energy-Saving Effect of the Measures

The analysis case is based on the energy-saving measures used to improve the level of energy performance of the referenced houses to reach that of the passive house (Table 5). The energy-efficient technology employed in the analyzed cases involved the enhancement of the airtightness and the

installation of the energy recovery ventilator because the airtightness of the reference building is poor compared to that of the passive house.

Case 1 represents the current state of the reference building. Case 2 is the case where the airtightness performance is improved. Case 3 assumes the installation of an energy recovery ventilator. Case 3-1 represents the energy recovery ventilation (ERV) system currently applied in Korea and Case 3-2 represents the ERV system proposed in the passive house standard. In Case 3, the infiltration rate is not considered because positive air pressure is generated during the operation of the ventilation system.

Figure 5 shows the results of the heating energy demand according to analyzed cases with energy conservation measures. In Case 2, the heating energy demand is 29.26 kWh/m²·year. By enhancing airtightness performance in Case 2, the heating energy demand can be reduced by about 29% compared to the existing buildings (Case 1). However, more than 14 kWh/m²·year of heating energy demand is required, compared to the passive house standard. Cases 3-1 and 3-2 showed heating energy demands of 8.72 kWh/m²·year and 8.47 kWh/m²·year, respectively, and the heating energy demand is reduced by about 79%. Consequently, the heating energy demand of the reference building can be reduced under the passive house standard through the application of the technology of Case 3-1 and 3-2, where the ERV installation and proper ventilation rate are controlled.

Table 5. Analysis cases of energy conservation measures (ECMs).

	ECMs	Infiltration Rate	Ventilation System	ERV (Energy Recovery Ventilator)		Construction
				Performance	Electricity Demand	
Case 1	-	1.0 [57]				Conc.
Case 2-1	Strengthen air-tightness	0.6 [70]	without	without		Wooden
Case 2-2						Conc.
Case 3-1	Install ERV	0	0.295 ach [71]	Cooling-effic.: 45%, heating-effic.: 70% [72]	2.15 kWh/m ² ·year	Conc.
Case 3-2				Enthalpy heat-effic.: min 75% Elec. power cons.: 0.45 W/m ² h [73]	1.34 kWh/m ² ·year

Figure 5. Heating energy demand for the energy conservation measures (ECMs).

5. Economic Analysis of ECMs

5.1. Payback Period and LCC Analysis

The details of the initial cost of each case are described here and shown in Table 6. In general, the cost of applying passive house technology can vary depending on the builder. In this study, additional cost data with application of each energy-saving measure are applied through consultation of the Passive House Institute Korea [74].

Table 6. Additional cost according to the ECMs.

Cases	ECMs	Structures	Additional Cost (USD)
Case 1	-	Concrete	0
Case 2-1	Strengthen the airtightness	Wooden	4490
Case 2-2		Concrete	1796
Case 3-1	Install ERV	Concrete	4041
Case 3-2	Install high performance ERV	Concrete	8980

The operation period of the reference building was set at 27 years with reference to the average life cycle period of residential buildings in Korea [75]. The value of the building's final disposal cost is set at 10% of the residual value [76]. The input data for the averaged maintenance costs are collected by the Korean government [77]. Case 3-2, with an ERV system satisfying the passive house performance criteria, showed the highest initial additional cost of USD 8980. The additional cost of Case 3-1, which satisfies the passive house performance criteria, was USD 4401. Since the ERV system satisfying the passive house criteria is not supplied in Korean market, most of the high-efficiency ERV system is imported from Germany. It imposes high additional cost for achieving passive house in Korea. The additional cost of Case 2-1, which shows improved airtightness compared to the reference building with its wooden structure, exceeds that of Case 3-1, with an additional cost of USD 4490, but does not satisfy the heating performance standard of the passive house. When the airtightness is improved by 0.6 ACH at 50 Pa of the concrete structure, the additional cost is the lowest at USD 1796, but the performance of the passive house is not satisfied.

Figure 6 shows the payback period based on the relationship between the additional investment cost and the energy cost reduction that is incurred according to the energy-saving measures of each case analyzed. Case 2-1 shows the longest payback period of 22.6 years. Case 2-2 showed the same energy reduction rate as that of Case 2-1, but the payback period was relatively short at 9.04 years, due to the low additional investment cost. In Case 3-1, assuming the Korean standard ERV system installation, the cost-saving rate by period was 35%, and the payback year was 8.92 years. Case 3-2, in which the passive house standard ERV system was used, showed a high cost saving rate (44%), but the payback period was 14.92 years due to the high additional investment cost.

The above results show that it is necessary to conduct a payback period analysis based on the cost savings considering the long-term as well as the initial investment cost, in order to make a reasonable decision about the energy-saving measures needed to achieve a passive house.

Table 7 shows the results of the LCC analysis according to the energy-saving measures of the reference building. Economic analysis results can be derived for LCC analysis by numerically converting the economic advantage that incurs during the life cycle of the building. Case 2-1, which only shows an improved wooden structure and airtightness, was the least efficient in terms of LCC (USD −71.18) as a result of economic advantage, due to low energy reduction compared to the initial excess investment cost. Case 2-2, which shows the same energy performance as that of Case 2-1 but assumes concrete construction, achieves a final economic saving of USD 9105, due to the low investment cost level of 1/3 compared to that of Case 2-1. Case 3, in which the ERV system is installed, showed a relatively high additional investment cost, but achieved a high building energy reduction,

resulting in a high economic saving level during the building operation period. The application of the Korean ERV system (Case 3-1) (which requires an additional investment cost of half that of the ERV system proposed in the passive house standard (Case 3-2)), offers the best economic advantage (USD 10,556). Among the analyzed measures, the measure (Case 3-1) controlling the ventilation rate through the installation of the Korean ERV system is the best strategy in terms of building energy performance and economic analysis.

Figure 6. Additional cost and payback periods of ECMs to achieve passive house.

Table 7. Economic analysis according to the ECMs.

	Base Case	Case 2-1	Case 2-2	Case 3-1	Case 3-2
Initial cost (USD)	204,963	(+4490)	(+1796)	(+4041)	(+8980)
Energy cost savings (USD/year)	N/A	198	198	452	602
Energy cost saving rate (%)	N/A	17%	17%	35%	44%
Economic metrics					
LCC savings (USD)	N/A	−71.18	9105	10,556	7410
LCC saving rate (%)	N/A	−0.03%	4.39%	5.13%	3.54%
Payback period (year)	N/A	22.6 year	9.04 year	8.92 year	14.92 year

5.2. Assessment of Incentive Policies

According to the Building Energy Efficiency Certification (BEEC) of Korea [78], the certification ranging from grade 7 to grade 1+++ (total of 10 levels), depending on the primary energy consumption of the building and the financial incentives for energy-efficient buildings is applied to buildings satisfying Grade 1 (less than 120 kWh/m²·year). Financial incentives of a 15% reduction in acquisition tax and a 3% reduction in property tax are provided when Grade 1 of the building energy efficiency criteria is met [79].

The effect of the incentive of energy-saving measures analyzed in this study was limited to the case of a primary energy consumption under 120 kWh/m²·year (1st grade of BEEC). Therefore, Case 2 was excluded. The incentive analysis was limited to the investment cost of the building. The reference building acquisition tax is 2.8% (USD 5436) of the initial investment cost, and the property tax calculated based on the tax base is USD 146.48. The end user would need to pay a total of USD 199,738.5.

Figure 7 shows the result of calculating the initial investment cost (including investment cost and tax) according to each energy-saving measure and the short-term economic advantage based on the acquisition of incentive. The figure shows the financial information about the costs borne by the end user by calculating the initial investment cost, taking into account the taxes and incentives of building construction. In Case 3-1, which is included in the incentive acquisition category, the total cost can be reduced by about 0.4% (USD 838.5) if incentive is supported. Consequently, Case 3-1 is classified as a passive house with an additional initial cost of about 1.85% (USD 3690) compared to the total cost of the reference building of Case 1. Incentive can be acquired in Case 3-2, in which the ERV system is installed, satisfying the passive house standard at a relatively high price in the Korean building market. The incentive benefit of USD 857.8 when compared to the initial cost, including the existing tax, provides a total initial cost of USD 208,120 for implementing Case 3-2. Practically, for the implementation of Case 3-2, the additional initial cost increase is USD 8381.8 (4.21%) compared to the total cost of the reference building.

Figure 7. Total initial cost including tax and incentive.

Willingness to pay (WTP) represents the payable range by investors. According to the results for WTP for low-energy buildings by Dapaah et al. [80] in Singapore, the results indicate that a stated WTP for low-energy buildings of 5% extra investment can be considered a rational decision. The additional cost of the analysis cases, reaching the passive house standard reviewed in this study (Cases 3-1 and 3-2), was about 1.85%–4.20%. This result indicates that the two cases are within the range the end users are willing to pay. Passive house implementation requires a higher initial investment cost than that of a conventional building, but reasonable initial cost through incentive economic saving will enhance end-user participation.

6. Discussion and Conclusions

The number of passive houses and zero-energy buildings being constructed in Korea is growing at the government level and in the green building market as a measure to reduce the rapidly increasing consumption of building energy. This study reveals the limited ability of the government building energy policy to accommodate the requirement of the building market. In Korea, the building market emphasizes the initial investment cost and, consequently, hinders the expansion of the number of

passive houses that represents low-energy building. The building market is affected by the government policy and the investors' interests. The absence of economic information required by the investor for decision-making is the most significant obstacle to the implementation of the passive house. Since the improvement of the physical performance of a building to reduce building energy consumption affects the increase of investment cost, the optimization of both energy saving and economy is needed [81].

Energy-saving measures based on building energy consumption are needed to derive appropriate energy reduction and investment cost optimization. Based on this information, investors require information on the investment costs of developing passive houses, economic information considering long-term economic benefit, and incentives policy.

In this study, the energy-saving measures needed to improve the performance of single-family houses in Korea to the level of the passive house standard, and the energy saving and cost increase were analyzed. In addition, the economic feasibility of various passive house energy-saving measures was analyzed in terms of the life cycle of the building.

The annual heating energy consumption of the reference single-family house in this study is 2.75 times higher than that of the passive house standard (15 kWh/m²·year). The application of energy-saving measures for passive house implementation resulted in an additional initial cost of 1.85%–4.20% compared to the reference building. In addition, the proposed passive house alternatives show a short payback period and LCC result compared to the reference building's life cycle period. The possibility of passive house implementation is high, and the passive house is acceptable, considering the WTP of Korean investors or end users.

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