SWC_ A Study on the Economic Analysis of Zero Energy Building Using Solar Photovoltaic Energy in Korea

KyoungEun You[1], YuRa Yun[1], SeokIl Kim[1], SungWoo Kim[1,2], SungWan Kim[1], MyungKyu Park[1,3]

[1] Korea Research Institute of Eco-Environmental Architecture, Korea (South)

[2] University of Seoul, Korea (South)

[3] Seoul University of Science and Tech, Korea (South)

Abstract

In South Korea, Zero Energy Building (ZEB) certification is currently being enforced to reduce building energy and greenhouse gas (GHG) emissions. In order to obtain ZEB certification, it is necessary to secure a self-sufficiency rate through renewable energy production based on annual primary energy requirements.

At present, in the case of electric power transactions of distributed power in South Korea, market transactions are avoided because the burden of transaction and administrative costs for market transactions compared to profits from electricity sales is high. Under such a situation, if the performance of a general building improves in accordance with the ZEB certification standards, various additional costs will inevitably arise. Therefore, it is necessary to examine the economic feasibility of ZEBs by certification grade.

In order to secure economic feasibility, this study reviews the means to secure economic feasibility through payback period (PBP), net present value (NPV), and sensitivity analysis to secure economic feasibility considering the simple payback PBP analysis that ignores discount rate and variables (passive additional cost, surplus power selling unit price, and renewable energy subsidy ratio) based on costs arising from energy saving.

Keywords: Zero Energy Building (ZEB), Certification, Distributed Resources, Renewable Energy, Solar Photovoltaic Energy, Passive House, Sensitivity, Economic Analysis, Payback Period (PBP), Net Present Value (NPV)

1. Introduction

The Ministry of Land, Infrastructure, and Transport Affairs in South Korea has been accelerating the discovery of and implementation efforts for reduction means by field. It has increased the national greenhouse gas (GHG) reduction target in response to the ongoing efforts of the international community to respond to the depletion of energy and climate change and to realize sustainable development.

Of these, the building field accounts for over 25% of national GHG emissions. In order to reduce the energy demand and GHG emissions from buildings with high reduction capacity available, the government has set up a stepwise dissemination and diffusion plan for mandatory Zero Energy Buildings (ZEB) from 2020 to 2030.

From 2017 onward, ZEB certification has been enforced in the country, which certifies buildings in five grades in accordance with the energy self-sufficiency rate by evaluating the primary energy consumption and primary energy production per unit area of buildings [Σ{(renewable energy production – the amount of energy required for renewable energy production) × the relevant primary energy conversion factor} / evaluation area].

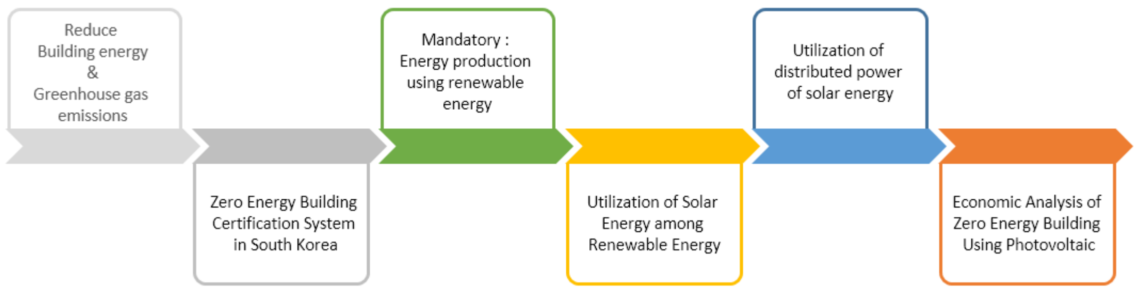

Fig. 1: The Flow Chart of Study

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In order to secure the self-sufficiency rate by securing energy production, it is preferentially necessary to select renewable energies that are superior in application to the inside of a building. Renewable energies include solar heat, photovoltaic power, wind power, hydroelectric power, fuel cells, and geothermal energy. Of these, the judgment of renewable energies that can be applied to distributed power in buildings was confirmed based on ease of application in a building and utilization of distributed power. Consequently, from among all renewable energy sources, fuel cells and photovoltaic power generation can be utilized as distributed power in buildings (Tab. 1).

In the domestic market, high installation costs of fuel cells and additional gas costs are major hurdles in an environment where the negative opinion on ZEBs is dominant due to various reasons such as lack of technology and reliability and associated increase in construction costs. Therefore, photovoltaic power generation is considered the most suitable renewable energy facility for economic feasibility analysis of distributed power at present (Tab. 2).

Tab. 1: Possibility of Utilizing Distributed Power as Renewable Energy

Category	Judgment to Apply Distributed Power in Buildings			Judgment of Economic Feasibility by Renewable Energy Source		
	Ease of Application in Buildings	Distributed Power	Non-Polluting	Ease of Application	Energy Efficiency	Remarks
Solar Heat	YES	NO	O	O	X	
Photovoltaic Power	YES	YES	O	O	X	
Fuel Cell	YES	YES	O	O	O	Gas cost incurred
Geothermal heat	YES	NO	O	△	O	
· Non Polluting : Energy source that does not cause pollution such as no environmental facilities, soot, noise, etc. · Ease of Application : Effective space and machine room availability · Energy Efficiency : High or low conversion efficiency from energy source to electric energy						

Tab. 2: Major Distributed Power Installation Cost and Additional Production Cost

Distributed Power Type	Installation Cost	Additional Costs Incurred in Production	Remarks
Photovoltaic Power	2,850,000 won/kW	None	Kotec Energy (Decebmer 2016, Public Procurement Service)
Fuel Cell	24,334,286 won/kW	Additional city gas cost (12.46~14.05won/MJ. for fuel cells, Seoul City Gas, February 2016)	Tokyo Gas/Panasonic (April 2015, Nikkei Technology)

However, in the case of private-use photovoltaic facilities, market transactions are avoided because of the burden of administrative expenses and transaction costs incurred for market transactions against electricity sales revenues. In addition, because of the high cost of power generation of distributed power, sufficient economic feasibility is not secured merely for the purpose of saving electricity charges.

The graph below presents the average price of power and the unit price of photovoltaic power generation in countries that have achieved grid parity (a balance point where the unit price of renewable energy is the same as that of existing fossil energy). In South Korea, the cost of photovoltaic power generation is higher than average power prices in countries that have achieved grid parity (Fig. 2).

Fig.2 Source: Deutsche Bank (2015), US average power prices (upper limit), Korea's average electricity price (average purchase price in 2014), Korea solar power generation unit price (average purchase price in 2014)

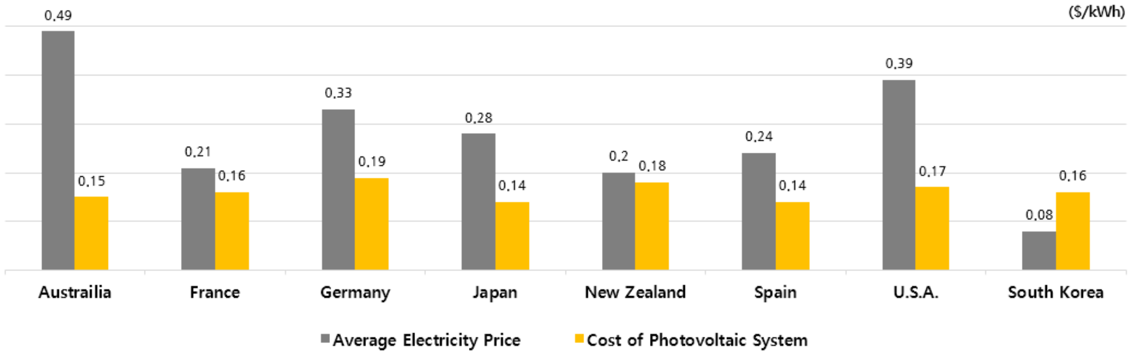

Fig. 2: Average Electricity Price and Cost of Photovoltaic System in Countries that have Achieved Grid Parity

In order to reduce GHG through a stable supply of ZEBs in South Korea. It is necessary to analyzing economic feasibility in terms of the cost benefit first has been deemed necessary. Therefore, in this study, the economic feasibility of additional costs incurred when a general building is strengthened to become a ZEB only for single-family houses with high GHG emissions per unit area of residential buildings is analyzed. Moreover, it is intended to utilize the results of the investment payback period (PBP) and sensitivity analysis to identify means to secure the economic feasibility in terms of the ZEB certification grade (Fig. 3).

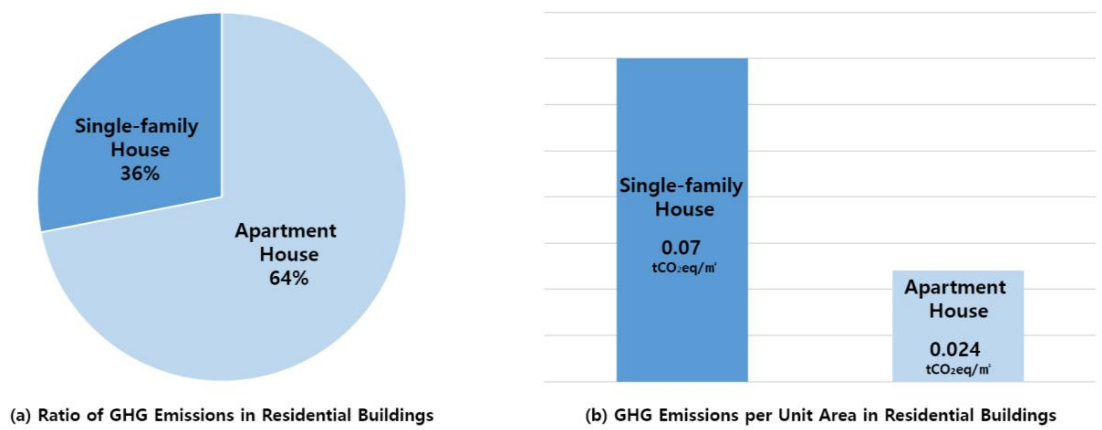

Fig. 3: Ratio of GHG Emissions in the Residential Sector and GHG Emissions Per Unit Area

2. Conditions of Models and Economic Evaluation Methodology

2.1 Conditions of Models

For general buildings, the following envelope conditions are applicable: According to the laws and regulations in 2016 (Attached table 1: Energy saving design standard of buildings, Notification 2015-11-08 of the Ministry of Land, Infrastructure, and Transport), infiltration must be 0.3 ach, which is the level of energy efficiency grade; applied boiler efficiency must be 85% for general boilers; and system air conditioners are COP 2.4, which represents energy efficiency grade 2. For passive buildings, the envelope condition is passive house level. Further, infiltration is 0.03 ach, system air conditioners are COP 3.4, and energy efficiency grade is 1+ (not including renewable energy).
The annual primary energy requirements per unit area of general buildings and passive buildings are 151.8 kWh/㎡ and 96.3kWh/㎡ (not including renewable energy), respectively, and the difference in energy requirement between the two types of buildings is 55.5 kWh/㎡.

Tab. 3: Common Architectural Summary of the Case Study

Target	Single-family house (Scale of two stories)
Major Heat Source Use Case	Gas boiler (heating, hot water supply), system air conditioner
Total Floor Area	155.25㎡

Tab. 4: Detailed Condition of General Building and Passive Building Models

Category		General Building Model	Passive Building Model
Envelope condition (W/㎡·K) (Level of laws and regulations in 2016)	Outer Wall	0.21	0.15
	Ceiling	0.15	0.11
	Floor	0.18	0.15
	Door	1.40	0.80
	Window	1.20	0.80
Infiltration (Energy efficiency grade)		0.3 ach	0.03 ach
Boiler Efficiency		Condensing 85%	Condensing 88%
System Air Conditioner COP		2.4	3.4
Ventilation Method		Natural ventilation	Natural ventilation
Energy Efficiency Grade		Grade 2	Grade 1+ (not including renewable energy)
Annual Primary Energy Requirement Per Unit Area		151.8 kWh/㎡	96.3 kWh/㎡ (not including renewable energy)

2.2 Basic Condition and Solar Equipment

Based on the calculation of additionally incurred costs according to the economic feasibility study (hereafter referred to as “research A”) in accordance with the Korean-type passive house certification model development, comfort index, and passive house construction cost analysis program of Passive House Institute Korea (hereinafter referred to as “research B”), the increase in the construction costs for general buildings for a construction area of 155.25 ㎡ is 22.38% for research A and 7.37% for research B. Since the difference in increased costs due to the additional costs of researches A and B is large, the calculation is based on a mean of 15.52%.

As a further consideration, for the main cost of each ZEB certification grade compared to the general building and passive building costs, distributed power installation subsidy is 670,000 won/kWp ($597/kWp). The annual surplus electricity is assumed to be all sales, and the sales unit price is 300 won/kwh (0.26 $/kWh). The annual maintenance cost is calculated as 1% of the initial investment cost of the photovoltaic power generation system. Based on 15.52% of average passive house construction costs for Study A and Study B.

At this time, the installation capacity and installation amount of photovoltaic power generation according to certification level of zero energy building are as follows (Tab. 5).

Tab. 5: Installation Capacity and Amount of Solar Power Generation System by Zero Energy Building Certification Level

ZEB Certification Grade	Energy Self-reliance (%)	Solar power system	
		Installation capacity (kWp)	Installation cost
1	100	3.35	7,303,000won ($6,196)
2	90	3.02	6,583,600won ($5,585)
3	70	2.35	5,123,000won ($4,346)
4	50	1.68	3,662,400won ($3,107)
5	30	1.01	2,201,800won ($1,867)

2.3 Economic Evaluation Methodology

In ascertaining the economic feasibility analysis result of ZEBs, it is necessary to consider the increase in the initial investment cost (passive additional cost + renewable energy installation cost + boiler replacement cost), annual energy cost savings (electricity amount fee savings + gas cost savings), initial investment cost payback (year), and energy cost zero (year) that are incurred when enhancing general buildings by grade in accordance with the ZEB certification standards. First, economic feasibility analysis is conducted by analyzing the simple PBP, which ignores discount rate (Tab. 6).

Tab. 6: Additional Cost and Economic Feasibility Analysis Method by ZEB Certification Grade

ZEB Certific-ation Grade	Energy Self-reliance (%)	Economic analysis for ZEB Certification			
		(a) Initial Investment Cost Increment (won)	(b) Annual Energy Cost Saving (won)	Initial investment Cost Recovery (year)	Net Zero Energy Cost (year)
1	100	Extra construction + Renewable energy equipment (including subsidy) + Replacement cost	Electric & Gas savings cost	(a) ÷{(b) +Surplus electricity selling price – Maintenance cost – Renewable energy equipment rental fee (option)}	(a) ÷{(b)+ Initial investment cost recovery – Annual energy cost saving}
2	90				
3	70				
4	50				
5	30				

In this study, technological progress and market changes in economic feasibility analysis, adopted investment payback analysis, and the net present value (NPV) method are considered from among the static analysis methods, which neglect changes in a country's economic structure. The analysis of investment cost payback is based on PBP analysis by analyzing the annual balance of the initial investment cost of distributed power (increase in construction cost, renewable energy facility cost, facility replacement cost) in terms of the savings in the electricity bill due to the introduction of distributed power facilities, profits from sales, maintenance expenses, and rental fee; the analysis ignores inflation rate. The analysis of NPV (cost zero – power) considers annual balance—including annual electricity cost such as the initial investment cost of distributed power, the reduction in electricity cost due to the introduction of distributed power facility, profit from sales, maintenance cost, and rental fee. The PBP, including the electricity cost, is analyzed. The inflation rate is the same as that in the investment cost payback analysis.

In addition, it is attempted to determine economic feasibility by designating passive additional cost, surplus electricity sales unit price, and renewable energy subsidy rate as variables for the investment cost payback and NPV analysis. The PBP is judged to be economically feasible at the time when the cumulative cash flow becomes positive (+), and the NPV analysis is judged to be economically feasible when the NPV is greater than or equal to 0 (Tab. 7).

Tab. 7: Sensitivity Analysis

Variable	(a) Extra Construction Cost for Passive Housing	(b) Surplus Electricity Selling Price	(c) Government Subsidy Tate for Renewable Energy
PBP method (year)	{(a) + Renewable energy equipment cost × (1 – (c)) + Replacement cost} ÷ {Energy cost saving + (b) – Maintenance cost – Renewable energy equipment rental fee(option)}		
NPV method (year)	$\sum_{t=0}^{N} \frac{C_t}{(1+r)^t}$ t: Period of cash flow, N: Investment period, r: Discount rate, Ct : Net cash flow at time Ct = {(a) + Renewable energy installation cost × (1 – (c)) + Boiler replacement cost} – {Energy cost savings at year t + (b) – Maintenance cost at year t -Renewable energy rent at year t (if applicable)}		

3. Analysis and Results

3.1 Simple PBP Analysis

As shown in the annual cumulative cost by ZEB grade compared to general buildings for a simple PBP, it is evident that the straight-line graph of zero-energy buildings is located below the straight-line graph of general buildings (current energy saving standard). In other words, ZEBs with high initial investment cost have a higher initial cumulative cost by year than general buildings; however, after a certain period, the higher the certification grade, the cost becomes lower than the cumulative cost in accordance with the number of years of general buildings (Fig. 4).

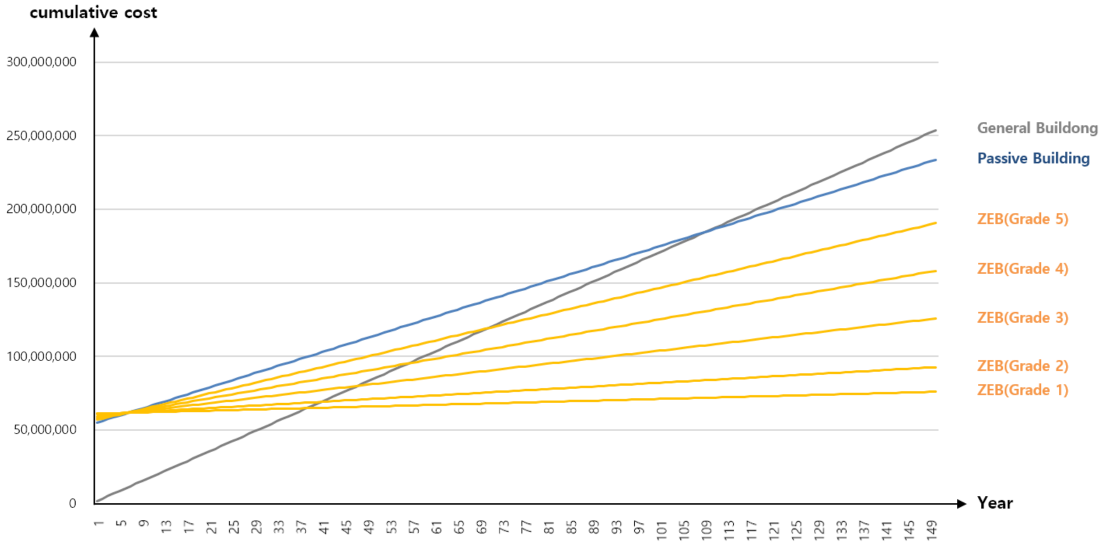

Fig. 4: Comparison of Cumulative Cost by ZEB Certification Classes for General Buildings

It is evident that when the surplus electricity sales unit price is 300 won/kWp, the PBP of the initial investment cost and the time when the cost becomes zero is from 38.4 years to 109.5 years as the ZEB certification grade is lowered.

Tab. 8: Comparison of PBP by ZEB Certification Grade for General Buildings

ZEB Certification Grade (Analytical independence rate)	**Surplus Power Sales (300 won/kWh)**	
	Initial investment payback (years)	**Cost zero (years)**
Grade 1 (100%)	**38.4**	82.6
Grade 2 (90%)	**40.9**	98.2
Grade 3 (70%)	**47.3**	162.8
Grade 4 (50%)	56.4	567.9
Grade 5 (30%)	70.6	impossibility
Passive buildings: Distributed power uninstalled (0%)	109.5	impossibility
General buildings (based on laws and regulations in 2016)	-	-

3.2 Sensitivity Analysis by Variable for Initial Investment Cost PBP

In the case of 22.38% of the buildings (research A), there is no ZEB certification grade given to the durability of the structure within 50 years. In the case of 7.34% of the buildings (research B), it is confirmed that the initial investment payback is possible within 25 years of photovoltaic facility durability for ZEB certification grades 1 to 4. In the case of 15.52% of the buildings (the median of researches A and B), the initial investment payback of ZEB certification grades 1, 2, and 3 within 50 years of structure durability is possible, but the initial investment cost payback within 25 years of photovoltaic facility durability is impossible (Fig. 5).

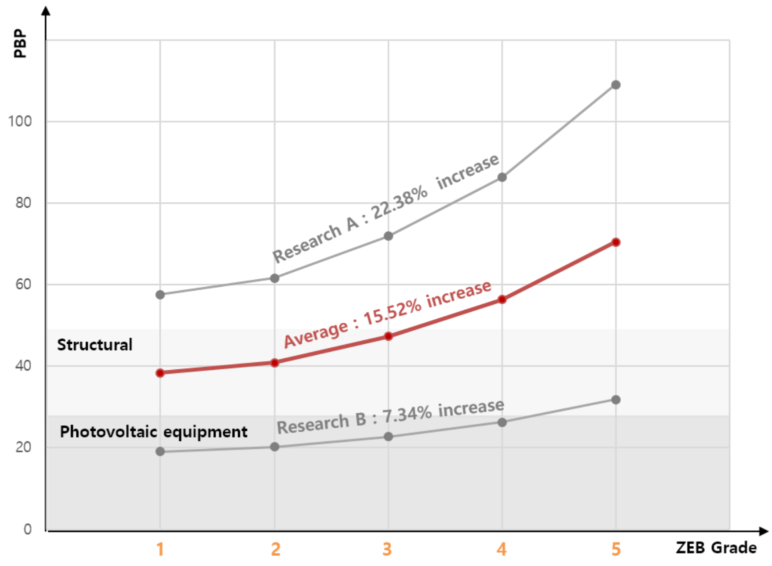

Fig. 5: Sensitivity Analysis in Accordance with Increase in Passive Cost

When the sales unit price is changed based on 15.52% (median of researches A and B), as a result of sensitivity analysis by ZEB grade, the initial investment cost payback is impossible within 50 years of the structure durability of single-family houses for 100 won/kWh. Moreover, it can be confirmed that the initial investment cost payback is possible in ZEB grade 3 for 300 won/kWh(0.26$/kWh) and grade 4 for 500won/kWh(0.43$/kWh). Moreover, it is also evident that the initial investment cost PBP is at least for approximately 25.5 years and takes up to approximately 30 years, depending on changes in the sales unit price (Fig. 6).

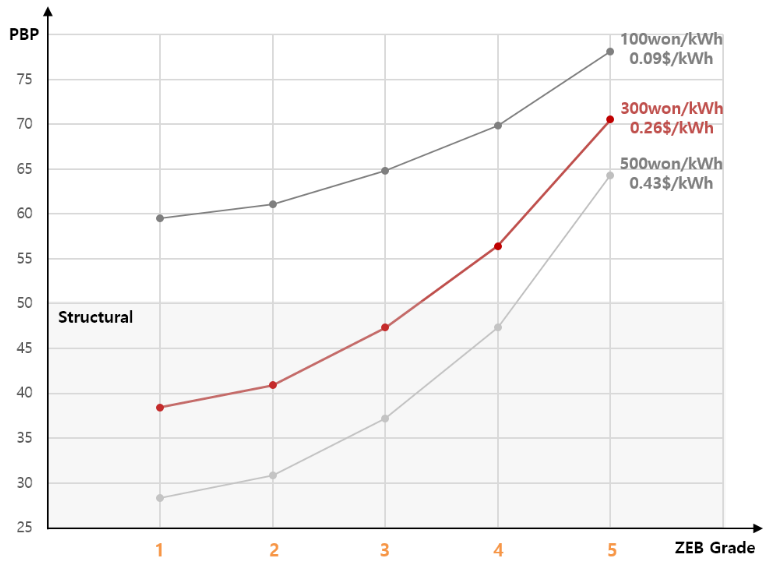

Fig. 6: Sensitivity Analysis According to Change in the Sales Unit Price of Surplus Power

The change in initial investment PBP of the ZEB certification according to the ratio of renewable subsidy is approximately 5 years. In the case of grades 4 and 5 of ZEB certification, the initial investment cost payback within 50 years of the durability of single-family houses is impossible. The sensitivity of each ZEB certification grade indicates that sensitivity to changes in the ratio of renewable energy subsidy is lower than sensitivity to increase in passive costs and change in surplus electricity unit price (Fig. 7).

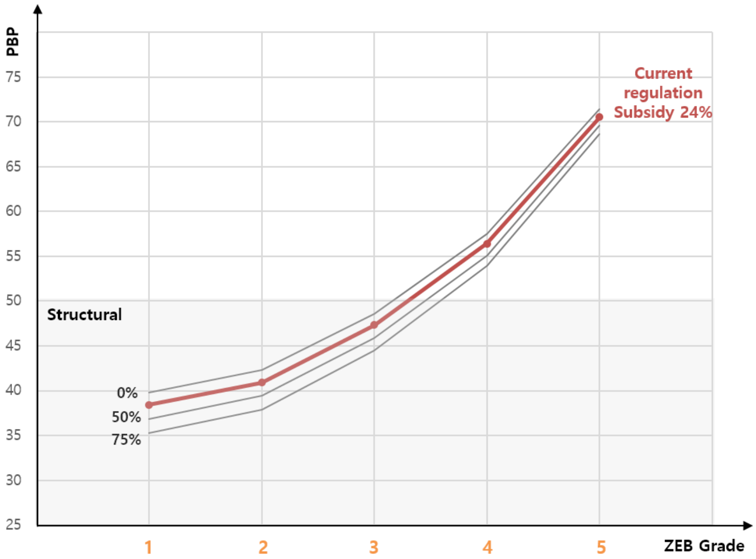

Fig. 7: Sensitivity Analysis in Accordance with Changes in the Ratio of Renewable Energy Subsidy

3.3 Sensitivity Analysis by Variable Regarding NPV

Net Present Value (NPV): One of the measures of the value of a business. The net benefits of each year from the time of initial investment to the end of the business are converted into present value. In other words, the net present value is greater than zero, the alternative can be judged to be acceptable.

· Present value of benefits-present value of costs = NPV

· If NPV>0, It is considered the business is feasible

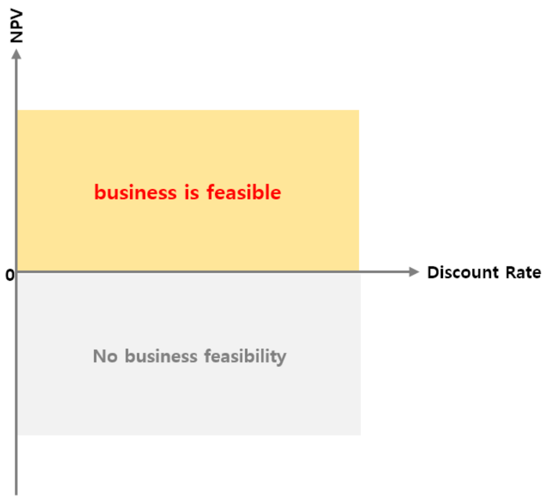

Fig. 8: Business feasibility assessment using NPV evaluation method

In the 50-year NPV sensitivity analysis, the variables for the passive cost increase rate were 22.38% for research A, 7.33% for research B, and 15.52% for the mean. In the graph, the X-axis represents the changes in discount rate, and the Y-axis represents NPV values. The NPV in research B is the highest, where increase in passive construction cost is the lowest. In the case of the researches A and B, at every discount rate, the NPV was found to be lower than zero, thereby indicating that it does not have economic feasibility (Fig. 9).

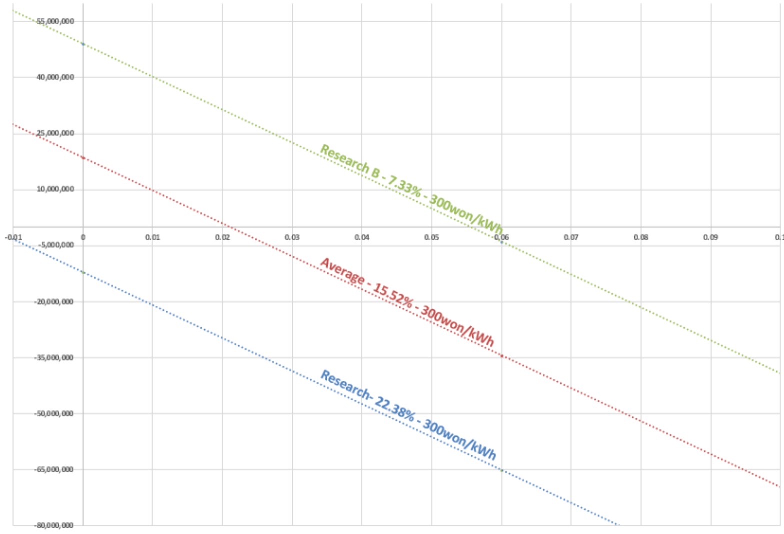

Fig. 9: Sensitivity Analysis in Accordance with Increase in Passive Cost

A 50-year NPV sensitivity analysis was conducted for 100 won/kWh(0.09$/kWh), 300 won/kWh(0.26$/kWh), and 500 won/kWh(0.43$/kWh) as surplus electricity sales unit price variables based on passive cost increase rate of 15.52%. The slope of surplus electricity sales unit price (⊿ cumulative cost ÷ Δ discount rate) is different, and the value of the slope of decreased cost is in the order of for 100 won/kWh(0.09$/kWh), 300 won/kWh(0.26$/kWh), and 500 won/kWh(0.43$/kWh). Moreover, the surplus electricity sales unit price of 100 won/kWh(0.09$/kWh) is not economical, and it was confirmed that economic feasibility can be obtained when the surplus electricity sales unit price is 100 won/kWh(0.09$/kWh)~300 won/kWh(0.26$/kWh) (Fig. 10).

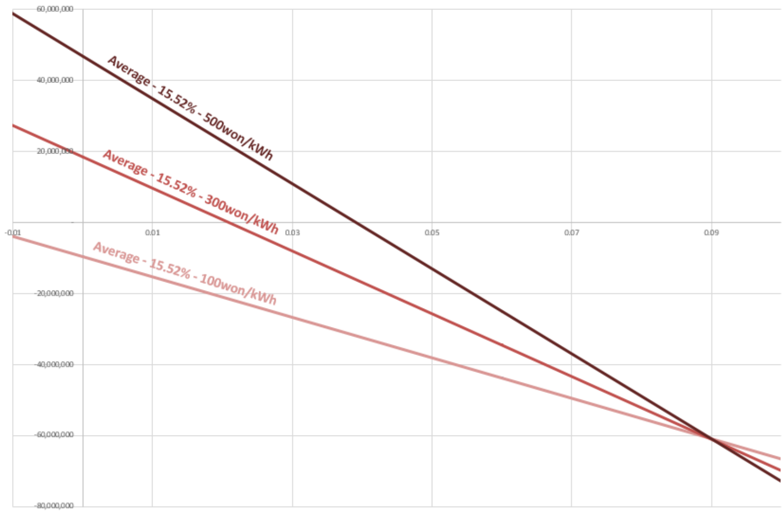

Fig. 10: Sensitivity Analysis According to Change in Surplus Electricity Sales Unit Price

A 50-year NPV sensitivity analysis was conducted for subsidy rates of 0%, 24% (current subsidy ratio), 50%, and 75% of the initial investment cost of the distributed power with subsidy rate on distributed power as variable, based on 15.52% of the average of increase in passive cost. The analysis indicated that the NPV of 75%, which has the highest subsidy rate, is the highest, and the NPV of 0%, which has the lowest subsidy rate, is the lowest (Fig. 11).

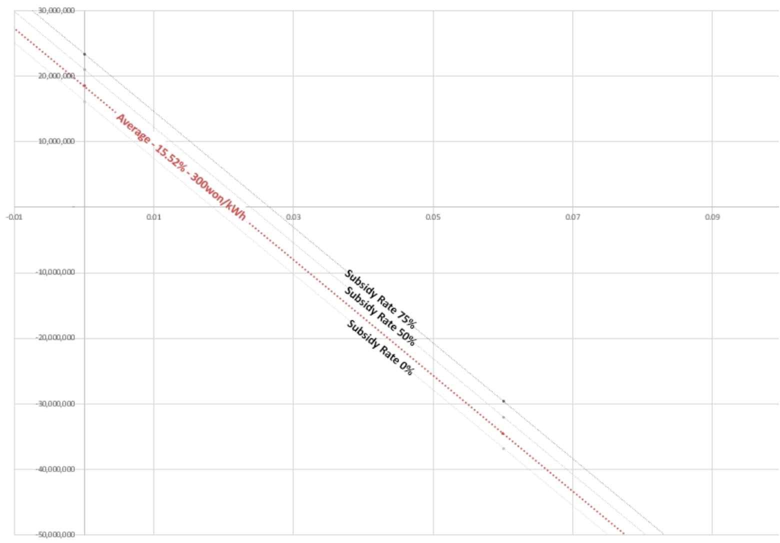

Fig. 11: Sensitivity Analysis According to changes in the Renewable Energy Subsidy Rate

4. Conclusion

In this study, the economic feasibility of the initial investment cost payback was assessed for ZEB certification grade, with 15.52% increase in construction cost, 300 won/kWh of surplus electricity sales unit price, and 24% of renewable energy subsidy rate for ZEBs. Consequently, it is necessary to acquire a self-sufficiency rate of grade 3 or higher, where the initial investment cost can be recovered within 50 years of the durability of the structure. In the case of cost zero, the grade that can offset the electricity cost and gas cost is 82.6 years.

In the results of the sensitivity analysis for PBP and NPV, the following variables were set (passive additional cost change, surplus electricity sales unit price change, renewable energy subsidy rate) to prepare the means to secure economic feasibility (Tab.9):

Tab.9: Summary

Variable	**Sensitivity Analysis**	
	PBP by Grade	**NPV Based on Grade 1 (50 years)**
Passive additional cost change	· Passive cost increase must be lowered to a range of 7.34% to 15.52% to recover the initial investment cost for structural durability (50 years) at all grades.	· Sensitivity is low in the order of passive cost increase > Surplus electricity sales unit price > Renewable energy subsidy rate. · In the analysis of the 50-year NPV, passive cost increase must be lowered to 15.52% to 22.38% to have economic feasibility in accordance with discount rate. · First, an economic feasibility consideration is required.
Surplus electricity sales unit price change	· In the case of surplus electricity sales unit price, it is possible to recover the initial investment cost for structural durability (50 years) only at grade 3 or higher at 300 won/kWh(0.26$/kWh) and grade 4 or higher at 500 won/kWh(0.43$/kWh).	· Surplus electricity sales unit price must increase to 100 won/kWh(0.09$/kWh) to 300 won/kWh(0.26$/kWh), which is economically feasible, according to the discount rate.
Renewable energy subsidy rate	· Sensitivity is lowest for changes in the renewable energy subsidy rate. · In all cases (subsidy 0% ~ 75%), the initial investment cost for the structural durability (50 years) can be recovered.	· Lowest sensitivity · The NPV becomes lower in the order of 75% > 50% > 4% > 0% of the renewable energy subsidy rate; it has economic feasibility according to discount rate in all cases. · Lastly, economic feasibility considerations are required.

In summary, in the case of a change in subsidy rate for the initial investment cost in distributed power relative to a change in the rate of increase in passive construction cost and the change in surplus electricity sales unit cost, it can be confirmed that sensitivity to change in values is relatively low.

This suggests that it is necessary to first consider economic feasibility about the change in increasing construction costs compared to general buildings for ZEBs to achieve zero cost through sensitivity analysis of three variables. Next, it is necessary to present an appropriate price for the present surplus electricity sales unit price.

Further, the decoupling phenomenon (decoupling refers to a phenomenon where the economy of one country or specific countries exhibits movements and economic flows that are different from universal global economic trends or trends in neighboring countries) between photovoltaic power generation sales unit price at a higher price than South Korea's cheap purchase price (KEPCO's electricity rates) compared to other countries has had a major impact on the results of this study.

This study is expected to be valuable as a case to present a means to a more secure economic feasibility using solar energy of other countries that display the decoupling phenomenon between purchasing unit price and retail unit price and that have an electricity wholesale market price that is similar to that of South Korea. It may also be used as a comparative data in countries where a subsidy policy is required or in countries with subsidy policies that are related to the government's installation of renewable energy.

5. References

Ministry of Land, Infrastructure and Transport, 2014. Green Building Masterplan I, South Korea.

Ministry of Land, Infrastructure and Transport, 2016. Green Building Support Act. 16418, South Korea.

Ministry of Land, Infrastructure and Transport, Korea Energy Agency, 2016. Energy Conservation Design Guideline of Building, Version 2015-1108, South Korea.

Ministry of Land, Infrastructure and Transport, 2016. Building Energy Efficiency Rate Certification and Zero Energy Certification Criteria, Version 2018-675, South Korea.

KEPCO Economy and Management Research Institute, 2016. KEMRI Electricity Economy REVIEW 2016 vol. 7, KEPCO, Jeollanam-do, South Korea.

Myungji University, 2014. Development of Korean Passive House Certification Model and Economical Evaluation According to Comfort Index, Korea Institute of Civil Engineering and Building Technology, Gyeonggi-do, South Korea.

Myong-ju, L., 2017. An Optimization Model of Korean Zero Energy Housing under the New Climate Regime, PhD thesis, Sejong University, Seoul, South Korea.

Minjun K., 2014. Economic Performance Evaluation of Cooling System Provided in Large Multiuse Buildings Using Renewable Energy, Seoul National University of Science & Technology, South Korea.

Josef A., 2013. Toward Net Zero Energy Solar Buildings, IEA SHC Task40/ECBCS Annex 52, IEA SHC.

Marszal, A.J. et al., 2011. Zero Energy Building—A Review of Definitions and Calculation Methodologies, Energy and Buildings, https://doi.org/10.1016/j.enbuild.2010.12.022.

Torcellini, P. et al., 2006. Zero Energy Buildings: A Critical Look at the Definition, NREL, U.S.

D'Agostino, D. et al., 2016. Synthesis Report on the National Plans for Nearly Zero Energy Buildings (NZEBs) Part 2, Joint Research Centre, European Commission.

Erhorn, H. et al., 2015. Nearly Zero-Energy Buildings Overview and Outcomes, Energy Performance of Buildings, MDPI, Switzerland.

Karsten Voss et al., 2010. Load Matching and Grid Interaction of Net Zero Energy Buildings. Euro Sun Conference, Austria.

Energy Efficiency and Conservation Division Agency for Natural Resources and Energy Ministry of Economy, 2015. Trade and Industry in JAPAN, Definition of ZEB and Future Measures Proposed by the ZEB Roadmap Examination Committee, Japan.