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Current Status of Old Housing for Low-Income Elderly Households in Seoul and Green Remodeling Support Plan: Economic Analysis Considering the Social Cost of Green Remodeling

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Abstract: In this study, the economic feasibility of green remodeling (GR), which could improve the health, safety, and energy of elderly households considering social cost, was analyzed. As a result, the net present value of GR was '−10,267 USD (49.7%)', which was found to be uneconomical compared to the total construction cost (20,981 USD, 100%) despite benefits of energy saving, carbon reduction, and air pollutant reduction. Based on this result, in order to expand GR for low-income elderly households, who cannot afford to perform GR, a GR support measure linked to the currently implemented energy conversion and old-age housing support policies was proposed. It allows the government to perform GR for low-income elderly households with 1/4 of the total construction cost. This result could revitalize GR to reduce greenhouse gas and contribute to housing stability for low-income elderly households who are vulnerable to COVID-19 and climate change.

Keywords: old housing; sick building syndrome; green remodeling; social cost; energy transition; housing stability policy

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1. Introduction

1.1. Background and Purpose

The World Health Organization (WHO) has pointed out the aging generation problem, where the global population over the age of 60 is expected to increase from 900 million in 2015 to 2 billion in 2050 [1]. Korea has become an aging society, with an aging rate of 14% as of 2017, and it is expected to reach 20% by 2025, at which point it will become a super-aging society. Recently, Statistics Korea predicted that this trend of aging in Korea will be accelerated more and more [2]. Due to the global COVID-19 pandemic from the end of 2019, "untact", non-face-to-face society (business, education, shipping, etc.), and non-face-to-face services (food, goods, drive-thru shopping, etc.) have quickly been established in Korea as the New Normal [3]. These social changes increase the staying time of residents in buildings, and they emphasize the importance of indoor environment (temperature/humidity/ventilation) and air quality, which directly affect human health [4]. In this regard, the housing condition of an aged house is affected by the indoor environment and air quality, and it is closely related to the health of the residents [5]. For example, high or low temperature indoors (summer/winter) causes cardiovascular diseases, high blood pressure, and respiratory problems [6]. Specifically, an imbalance in room temperature or humidity leads to mold growth, which may cause respiratory disease and lung cancer [7]. In addition, the problem of noise from the outside intruding into the house may also cause cardiovascular diseases, sleep problems, and cognitive impairment [8]. Improving the energy efficiency of old houses is known to be a good strategy for enhancing the housing condition of a house in the long term [9]. For example, improving building envelope insulation, windows, and heating-cooling equipment may enhance the indoor thermal environment, and making high-performance window improvements using sealing materials (airtight tape, etc.) may reduce the external noise problem [10]. The total heat exchange ventilation system improves the indoor air quality by introducing purified outside air [11]. Insulation, windows, high-efficiency air conditioning systems (boiler/EHP), and total heat exchange ventilation systems are actively used as the elementary technologies of GR (Green Remodeling) for improving the energy performance of old buildings. These measures for improving the energy efficiency of old buildings are referred to using various terms such as energy retrofit and green renovation, but in this paper, the term 'GR' is used. Further, 'GR' in this paper includes deep energy retrofitting, such as improving insulation, windows, air condition, ventilation, etc., rather than a single measurement for performance improvement.

In April 2019, in a report on the perspective of the clean energy transition, the IEA highlighted the importance of energy transition through GR of old buildings [12]. The GR is used as a core energy saving policy in the building sector for energy conversion and greenhouse gas reduction. However, there are several barriers to applying GR policy for reducing greenhouse gas emissions, so many countries are using various measures to overcome these barriers [13,14].

The most representative barriers are economic feasibility, such as high initial construction cost and low subsidy. Technical skill level, information imbalance, uncertainty, and rebound effect have also been mentioned as barriers [13–15]. To alleviate these barriers and implement GR, many countries are using construction cost support, low-interest loans, technical support, and various types of promotional support according to the energy improvement performance of old buildings as auxiliary policies [13,14]. Many other research papers involving GR suggest an optimal GR planning direction by approving the energy effect of GR and analyzing economic feasibility to alleviate the aforementioned policy barriers. First, simple remodeling action (insulation replacement, windows replacement or air conditioning replacement) can bring about lower results than expected in terms of energy and cost effectiveness as compared to GR (insulation + windows + HVAC + ventilation) [16]. These relationships can be confirmed from empirical GR analysis cases in Europe and the United States [17–19]. The cause of this is that using a simple measure that is not coordinated with other aging elements (such as walls, roofs, windows, ventilation, and air conditioning) can lead to a lower energy saving effect than expected, due to the deteriorated quality of thermal bridges and elements that were not improved after construction [20]. By contrast, the GR provides energy performance to new construction levels by examining the deterioration of the target building in advance and planning all elements that require improved consideration of the latest legislations (insulation, thermal bridges, air tightness and ventilation, and mechanical and electrical installations). Accordingly, the EU Commission also recommends GR in consideration of reliable energy efficiency improvement and economic feasibility for the owners and investors of old buildings [21].

However, this GR is not a measure that can be adopted by all owners of old buildings, because of the high initial construction cost which requires about 10 years (relatively long term) to recover the construction cost [22]. This is particularly true for low-income elderly households who experience a relatively large impact on energy bill burden, indoor environment, and air pollution. Although elderly households desperately need GR, it will be difficult to improve energy, indoor environment, and air quality without government support.

This paper investigated the aging status of buildings as well as the energy performance and usage status of nine old houses for low-income elderly households in Seoul, Korea. Among them, one old house was selected, and the total construction cost required for GR and energy savings before and after GR were analyzed. Based on the results of these analyses, an economic analysis was conducted in consideration of social costs. Then, to activate GR for low-income elderly households, a GR support plan that links the current energy transition with the low-income old housing support policy was proposed by utilizing the health, safety, and energy improvement effects of GR. This support plan is expected to contribute to an improved residential environment along with activation of the GR from the GR support for low-income elderly households who are vulnerable to COVID-19 and climate change.

The unique features of this study are that when planning the GR of old housing for low-income elderly households, energy, health, and safety factors that were considered as housing characteristics of elderly households were all reflected in the construction cost to analyze economic feasibility. Therefore, an effective housing stabilization plane was proposed by integrating the old housing support policy for low-income elderly households with the direct and indirect effect of GR.

1.2. Procedure and Method

The research procedure was divided into four stages: Section 2 describes the literature review, Section 3 details the target selection and GR plan, Section 4 discusses the economic analysis, and Section 5 presents the GR support concept proposal. In the literature review in Section 2, previous studies were reviewed to derive health problems and the causes for the residents of old houses, and architectural methods that could be used to improve these issues were summarized. Then, factors for safety improvement were investigated in consideration of the residential characteristics of elderly households, which may be the most vulnerable group among residents of old houses. Finally, the scope of energy elements and performance level of improvement for old houses were investigated, and the improvement scope and performance level of buildings and facilities that were suitable for the characteristics of old houses in Korea were summarized. The GR range of this study based on the review includes health, safety, and energy performance improvements in consideration of the residential characteristics of low-income elderly households.

In Section 3, the status of aging houses of low-income elderly households in Seoul, Korea was investigated, and target buildings were selected for GR analysis. First, the aging status of the houses in which the vulnerable class (such as elderly households) with less than 70% income reside among the old single houses and multi-family houses that have been in Seoul for more than 30 years was investigated and analyzed. Next, GR target buildings were selected, and the scope and methods for GR improvement were summarized based on the results of a literature review and on-site investigations. This GR plan includes building and facility elements applied in terms of health, safety, and energy. The performance level of these elements was planned in consideration of regulations and construction costs.

In Section 4, the economic analysis considering social costs was described. First, the total construction cost was derived by calculating the construction costs of each element in the GR plan. For energy analysis, the annual energy and reduced amounts of the greenhouse gas (CO_2) for the target building before and after GR were calculated using ECO-2 (Korean Building Energy Efficiency Rating Program). To analyze the economic feasibility, the annual energy saving cost (benefit of residence) was calculated by converting the amount of the energy into the electricity rates for houses. The social cost was calculated by converting the reduction amount of greenhouse gas (Social Benefit-(1)) and the reduction effect of the air pollutant (Social Benefit-(2)) into cost [23]. For the economic feasibility analysis, the residence benefit and the social benefit according to the GR of the old house compared to the total construction cost of the GR were analyzed and compared using the Net Present Value (NPV) method. The NPV method was used to analyze economic feasibility, because it can suggest the present value of future accrued benefits, and the results of its analyses can be used for other analyses [24].

In Section 5, a GR support plan was proposed in which the housing stability policy and the energy conversion policy for low-income elderly households were mixed based on the analysis results. Figure 1 shows a flowchart of the research contents according to the research procedure.

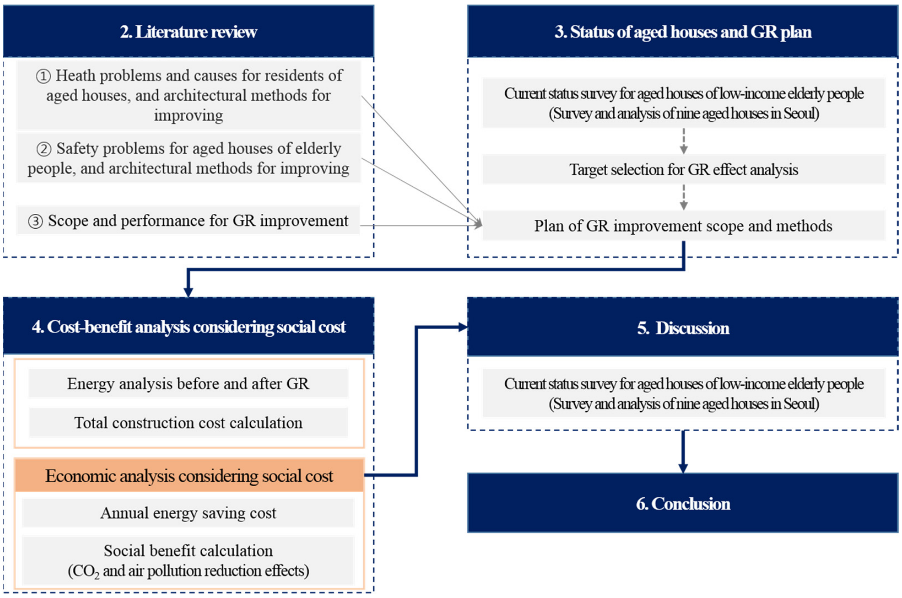


Figure 1. Research flowchart.

2. Literature Review

In the literature review of previous studies, three aspects of old housing were investigated. First, the causes of health problems in old houses and architectural methods to improve them were investigated; second, using the 2017 Seoul housing situation survey data, factors for improving the safety aspect of the elderly households who are vulnerable groups were derived; and third, GR factors and performance levels in terms of energy were summarized. The results of this survey will be used as basic data when planning the GR of old housing for low-income elderly households.

2.1. Causes of Health Problems in Old Houses and Methods of Architectural Improvement

Sick Building Syndrome refers to a phenomenon wherein the indoor air quality and indoor environment can adversely affect the health of the residents [25]. Outside air polluted by PM2.5 and PM10 enters the room without being purified, which can cause respiratory diseases in the residents [26,27]. In addition, various damages may be caused to residents due to damp wallpaper and mold growing inside the wall, various harmful gases leaking from the grain pipe, and VOCs (volatile organic compounds) that may be present after interior construction [8,25,28].

First, the unexpected inflow of polluted outdoor air by particle materials (PM2.5, PM10) into the room is largely affected by the quality of the aged windows [27]. The inflow of polluted outdoor air can be reduced by replacing old windows and sealing window edges. Mold growing indoors mainly occurs on the side walls (where the outside and the wall come into contact) according to the temperature difference between the inside and outside, and this difference worsens when the indoor air is not ventilated. The vulnerable areas to indoor dewing and mold are mainly the space between furniture (closets, etc.) and the wall and/or in the space between the wallpaper and the wall. The main cause of this problem may be the wall heat bridging and lack of indoor ventilation. For an architectural method to improve this problem, an insulation construction without thermal bridges (external insulation) and a total heat exchange ventilation system suitable for the purpose may be applied [29,30]. The leakage of methane gas, ammonia gas, carbon monoxide, and carbon dioxide from old drains or gas pipes may cause headaches or dizziness. To solve these problems, old pipes should be regularly cleaned and replaced [30]. Specifically, it is necessary to properly manage and replace the trap protecting the water seal which can block the backflow of odors to facilitate drainage and manage aging vent pipes to protect the water seal. There is a possibility of causing chronic diseases such as headaches and allergies due to organic compounds such as acetone, benzene, and formaldehyde generated from materials and furniture that is newly installed due to repair activities, such as interior construction and furniture replacement, while maintaining the building. This problem may be improved by regular ventilation and the use of environment friendly materials [31,32].

According to the Health and Home Upgrades research report by DOE (U.S. Department of Energy) in February 2017, housing environment has a significant impact on resident health, and improving the energy performance and ventilation facilities of old buildings also enhances the energy and health of residents [28]. As an empirical case of health improvement by GR, Beysse et al. analyzed the health improvement effect of 40 elderly households after GR in the US. As a result, respiratory diseases, overall health problems, indoor environment (temperature/humidity), indoor air quality, and musty smell from pipes were all improved [33]. Ahrentzen et al. performed GR (including eco-friendly finishing material and furniture) for 57 aged houses of low-income elderly citizens in the United States. As a result, the indoor environment (temperature/humidity) and indoor air quality (formaldehyde, particle matter, etc.) were improved, and the overall health of residents was enhanced as well [34]. In addition, in the analysis of a number of GR empirical cases, the resident health was enhanced from the improvement of the indoor environment and indoor air quality after GR [35–37].

In summary, energy saving and improvements in both indoor environment and indoor air quality are some of the expected benefits of reforming insulation, windows, heating and cooling, and ventilation facilities which are general elements of GR. Further, the results showed that it can help improve the indoor environment to enhance the health of residents by applying eco-friendly materials and furniture, as well as proper management and replacement of old pipes when improving the interior space.

2.2. Review of Housing Improvement Factors for Elderly Households among the Vulnerable Classes

To capture the housing situation survey in Seoul in 2017, the factors necessary for housing improvement were investigated by reflecting the characteristics of elderly households [38]. A survey was conducted that covered a total of 10 items, as shown in Figure 2. In the results of a study comparing owned houses to rented houses, 'Nonslip Floor Materials', 'Indoor Emergency Bell', 'Door Knobs', and 'Support Knobs' appeared at high proportions. Among 10 items, except for the 'Indoor Emergency Bell' and 'Safety Knobs', these items are optional items which can be reflected in a GR plan without affecting the cost and the plan. Therefore, when planning a GR improvement model in this study, the items of 'Indoor Emergency Bell' and 'Safety Knobs' were included in consideration of the characteristics of elderly households of aged houses, and they were reflected in the construction cost.

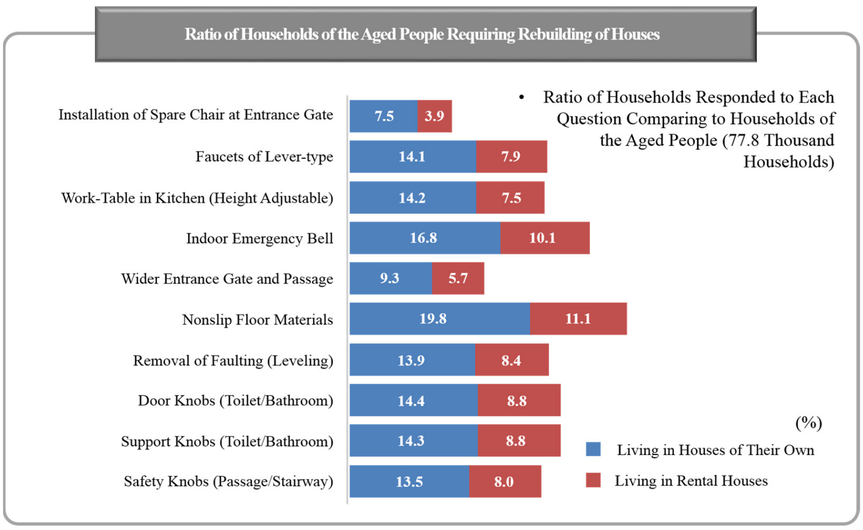


Figure 2. Ratio of items required for rebuilding houses of elderly households.

2.3. Investigation of Energy Performance Improvement (GR) Factors and Performance Level of Aged Houses

Recently, the research on energy performance improvements of aged buildings has mainly focused on energy saving by total GR or the cost efficiency of zero-energy GR, rather than the energy efficiency of individual items. In particular, to increase the utilization of GR research, various studies have examined GR strategies for apartment houses, school facilities, and business facilities, which are in high demand [10,39–41]. The improvement scopes and performances of these precedent studies have differences in climate by region, technology level, and residential environment, so care should be taken when adopting the applied technology for use in various settings. Accordingly, in this study, the performance of the improvement scope was considered by referring to the GR guidelines issued by the Korean government.

In 'Guidelines for the Establishment and Implementation of Urban Renewal Revitalization Plan for Urban Renewal New Deal Projects' published in August 2018, the Korean government disclosed GR cases, scope of technical elements, and recommended performance of aged houses [41]. The scope of improvement in the guidelines includes the replacement of roof/exterior wall insulation, windows (including entrance doors), air conditioning equipment, indoor LED lightening, and renewal of façade design. These need to be additionally reflected when planning the GR improvement model, because the literature review does not include the consideration of a ventilation system or sealing system for resident's health. This guideline provides performance improvement standards for each GR item, and it can be used to determine the performance level. Table 1 presents the improvement in factors and performance for each item. 'Bad' refers to the performance of the aged building, 'Good' refers to the performance of a passive house in Germany, and 'Recommended' refers to the performance level of each item of the GR plan considered in this study.

Table 1. Improvement in factors and performance in terms of energy consumption [41].

Locations	Level of Performance/Location		
	Bad	**Recommended**	**Good**
Insulation of Roof ($W/m^2 \cdot K$)	0.33	0.15	0.08
Insulation of Exterior Wall ($W/m^2 \cdot K$)	0.45	0.22	0.13
Insulation of Window ($W/m^2 \cdot K$)	2.9	1.41	0.75
Lighting Density (W/m^2)	17.29	9.46	3.40
Heating/Cooling	-	A Product of Class I of the Energy Consumption Efficiency	
Amount of Energy Consumption ($kWh/m^2 \cdot y$)	228.10	167.43	55.0
Amount of Primary Energy Consumption ($kWh/m^2 \cdot y$)	267.20	214.43	150.7

Finally, the use of IoT-based smart home technology for small elderly households is spreading [29]; however, the GR plan described in this study minimizes the automatic control facilities and applies only the items related to safety (emergency bell linked to mobile phone) while considering the cost aspect.

Figure 3 summarizes the problems in health, safety, and energy aspects and the direction of architectural improvement considering the characteristics of residents of aged houses from the literature research. Figure 3 shows that the architectural method for enhancing the health problems of aged houses and the method for improving the building energy performance have many items in common. Based on this, it is clear that performing the GR described in the literature review has the effect of enhancing the health problems of residents. However, the GR scope of this study considering the health and safety of elderly households should be additionally applied to the material selection and replacement of sanitary piping, and the additional installation of various knobs, non-slip pads, and emergency bells, along with the removal of faulting should be considered based on the fact that the residents are elderly people. The results of this survey will be used in a GR plan considering health, safety, and energy after investigating the status of aged houses of low-income elderly households.

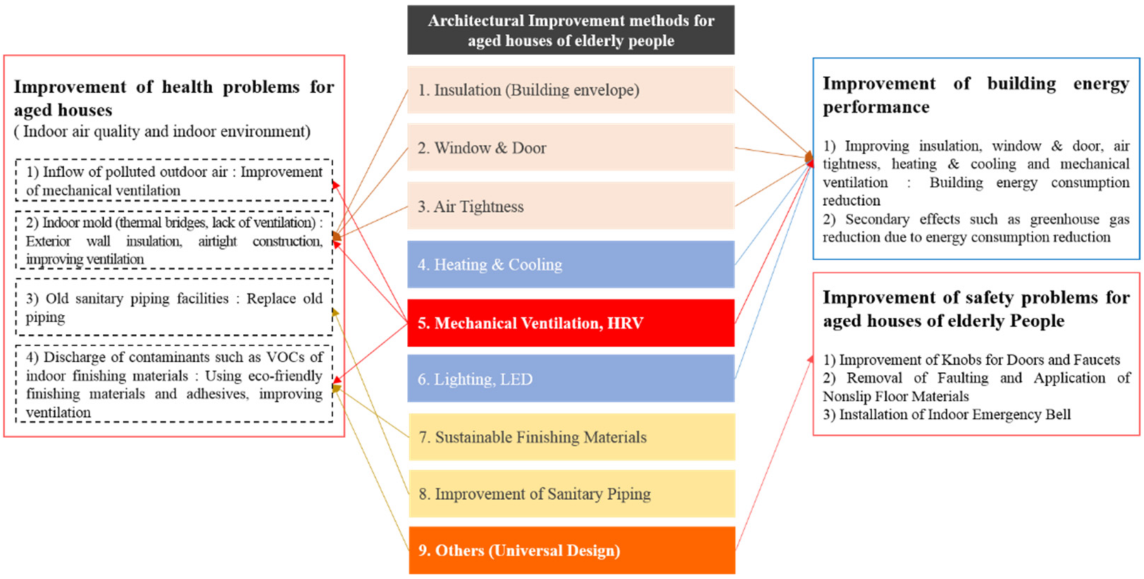


Figure 3. Issues associated with aged people in households of the old houses and the orientation of improvement in parts of the GR.

3. Current Status Survey and GR Plan for Aged House of Elderly Households in Seoul, Korea (Scope of Improvement and Performance)

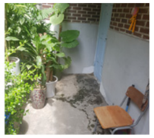
To investigate the current status of aged houses of elderly households in Seoul, the sites were surveyed with the project implementer for about two months with the cooperation of the 'Hope home repair project' of Seodaemun-gu, Seoul and the 'Structural safety status survey project' of Dongjak-gu, Seoul. More than 20 aged houses were investigated, and nine households were found to be suitable for this study.

Accordingly, in this section, common characteristics were derived by summarizing the aging status and problems of nine buildings of low-income elderly households. Among them, buildings that could be used to analyze the improvement effect by GR were selected as the target sites.

3.1. Survey on Current Status of Aged Houses for Elderly Households in Seoul

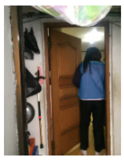
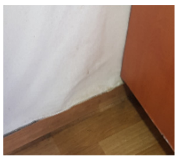
Table 2 summarize the building status, resident information, and building energy performance of aged self-owned houses or aged multi-family houses in which elderly households reside. As shown in the survey results, most elderly households living in aged houses for around 30 years were women over 70 years old, and they often lived on the lower floors (1st floor) with inconvenient movement and relatively insufficient ventilation and light.

Table 2. Results of survey on sites of old houses of households of aged people.

Items		Results of Survey on Each Household									Common Feature
		Household #1	Household #2	Household #3	Household #4	Household #5	Household #6	Household #7	Household #8	Household #9	
Building Information	Selected House										Single house and lower floor of multi-family house
	Location	Hong-je Dong 304-25	Hong-je Dong 287-72	Hong-je Dong 285-34	Sadang-Dong 275-15, 1	Sadang-Dong 275-15, 2	Sadang-Dong 249-45	#4 Ganho-Avenue 37, 301	Ganho-Avenue 28-4 Ground Floor (Semi-Basement)	Pobangteo-Road 18, 101	Hongje-dong and Sadang-dong
	Year of Completion	1991	1990	1987	February, 1972	February, 1972	March, 1972	April, 1991	March, 1993	January, 1992	Average service life of more than 30 years
	Structure	Brick	Brick	Brick and reinforced concrete	Brick	Brick	Brick	Brick	Brick	Brick	Brick
	Exterior Finishing	Face brick	Face brick	Face brick	Face brick and partial painting	Face brick and partial painting	Brick and painting	Face brick and painting	Face brick and painting	Face brick	Painted brick (efflorescence and crack)
	Interior Finishing	Wallpaper (Good)	Wallpaper (Moderate)	Wallpaper (Moderate)	Wallpaper (Good)	Wallpaper (Poor)	Wallpaper (Moderate)	Wallpaper (Moderate)	Wallpaper (Moderate)	Wallpaper (Moderate)	Wallpaper
	Remarks	Blistered wallpaper, Toilet threshold: 500 mm, (Disordered behavior of occupant)	Mold/dewing on side walls and boiler room observed	Mold/dewing in common-use toilet (Disordered behavior of occupant)	Windows, exterior finishing, and entrance gate require complementary works	Dewing and mold on side walls were observed	Partial remodeling works completed	Boiler and windows in main living room became obsolescent	Boiler and windows in main living room became obsolescent	Windows in all rooms became obsolescent	Immediate renewal due to mold, and dewing due to aging of building
Residential Information	Occupied Floor	Ground floor (House of two stories)	Second floor (House of three stories)	Ground floor (House of three stories)	Ground floor (One-story house)	Ground floor (One-story house)	Ground floor (One-story house)	Third floor (House of three stories; 8 households)	Ground floor (House of three stories; 4 households)	Second floor (House of three stories)	Lower floor
	Area of Occupation	-	-	-	28 m^2	32.93 m^2	27.37 m^2	30 m^2	15 m^2	32 m^2	Avg.: around 25 m^2
	Type of Residence	Rental (Monthly)	Rental (Monthly)	Rental (Monthly)	One's own house	One's own house	Rental (monthly)	Rental (Monthly)	Rental (Monthly)	Rental (Monthly)	Monthly rent
	Resident	Female (Age 70)	Female (-)	Female (Age 79)	Male (age 75) and a daughter	Female (age 65) and a son	Female (Age 73)	Female (Age 70)	Female (Age 60) and another one, husband	Male (Age 86)	Avg.: 70 years or more
Performance of Energy Consumption of Building	Insulation	EPS (Expanded Polystyrene) 50 mm	EPS 50 mm	EPS 50 mm	EPS 50 mm	- (None, the domestic regulations pertinent to insulation were stipulated after 1979)		EPS 50 mm	EPS 50 mm	EPS 50 mm	Dewing/mold
	Windows	Wood 3 mm and Aluminum 3 mm	Wood 3 mm and Al 3 mm	Wood 3 mm and Al 3 mm	Replaced—with PVC (Polyvinyl Chloride) double window	Wood 3 mm and Al 3 mm	Replaced—with PVC double window	Wood 3 mm and Al 3 mm	Wood 3 mm and Al 3 mm	Wood 3 mm and Al 3 mm	Sealing deterioration and dewing/mold
	Main Entrance Gate	No windbreak structure									Deterioration of sealing and energy performance
	Cooling	PAC (Package Air Conditioner)	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	Cooling: air-conditioner Heating: floor heating
	Heating	Gas boiler	Gas boiler	Gas boiler	Gas boiler	Gas boiler	Gas boiler	Gas boiler (Replacement needed due to obsolescence)	Gas boiler (Replacement needed due to obsolescence)	Gas boiler	
	Hot Water Supply	Electric water heater	Electric water heater	Electric water heater		Electric water heater					
	Ventilation	None									Vulnerable to PM
	Others	Requested rental apartment	-	Requested subsidy for housing expense	Requested installation of the main gate of house	-	-	Improvement of boiler and windows was planned			No safety knobs such as handrails

Dewing and mold, both of which have substantial effects on the health of residents in terms of building function and age, were found in all except the two remodeled houses (No. 4 and 6). There was a household (No. 3) with a public restroom and a household (No. 1) with an indoor rest room that had thresholds higher than 500 mm, despite the inconvenience of mobility. In terms of building energy and indoor air quality, all households had very poor insulation. Regarding the windows, all except two households were equipped with a combination of wooden single windows and AL single windows, so the insulation performance was less than 1/3 of the current legal standard performance. As the window frames have been used for more than 20 years, the air tightness performance was very weak. In addition, the front doors of all households were not equipped with a windproof structure, and there were no ventilation facilities at all. This was expected to have a significant negative impact on the health of elderly people, who are relatively vulnerable to particle matters and indoor air pollutants. Finally, regarding the heating and cooling facilities, all households were equipped with wall mounted air conditioners for cooling and boilers for heating using urban gas. Some households had outdated cooling/heating equipment, but there was no problem in usage. Table 3 presents images of major defects such as dewing and mold, a restroom in need of improvement, old window sets, and household front doors.

Table 3. Survey cases of defects in aged houses.

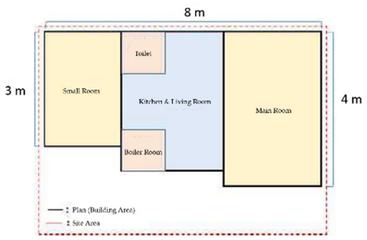
Dewing and Mold	Poor Toilet Threshold	Obsolete Set of Windows	Front Gate of Households
  (Above): Household #2 (Below): Household #3	  (Above): Household #1 (Below): Household #3	  (Above): Household #6 (Below): Household #7	  (Above): Household #2 (Below): Household #3
Interior Finish: Wallpaper Flutter	**Water Leakage**	**Safety (Electricity)**	**Others (Thermal Bridge and Airtightness)**
  (Above/Below): five households	  (Above): two households (Below): seven households	  (Above/Below): three households	  (Above): three households (Below): two households

3.2. Selection and Status of Target Sites for GR Effect Analysis

According to the site survey, the low-income elderly households were living on the lower floors of single-family or multi-family houses with monthly rent or that they owned themselves. Among them, residents of multi-family houses that were paying monthly rent requested relocation to a public rental apartment or housing cost support rather than facility improvement. By contrast, residents in their own aged house wanted subsidies for facility improvement or full facility improvement. In the case of owned single-family households, there was a problem in new construction and sale because the site area was small (less than 33 m^2) and it was located in a dead-end alley. To solve this problem, it may be an option to proceed with the remodeling by consulting with the neighbor of the adjacent site, but this is not easy.

Although all households surveyed require housing stability by facility improvement, by considering problems such as (1) self-ownership or rental, (2) relocation of residential households after facility remodeling, and (3) the scope of facility remodeling, the houses with clear land and architectural boundaries among self-owned houses were selected as the target buildings for GR analysis of aged houses. From the households surveyed, three households were single-family houses, and among them, No. 4 and 5 were candidates. No. 4, which has a relatively clear boundary of the building area on the site, was selected for analysis. Even though No. 4 was renewed by some facility improvements such as a window renewal and interior-exterior finishing renewal project in July 2019, there were no improvements in building energy, indoor air quality, or safety, except for windows. Table 4 presents the status of No. 4 after facility improvement.

Table 4. Cases of the survey on defects of old houses.

<table>
<tr><th>Land and Plan of an Old House</th><th colspan="2">Exterior/Interior Improvement in Finishes</th><th>Improvement of Window</th></tr>
<tr><td>
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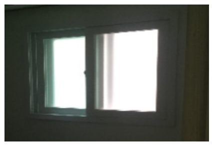
</td><td>
</td></tr>
<tr><td>Formation of house plan via actual measurement at site</td><td>(Above): Front view
(Below): Back view
Paint finish (only for main entrance)</td><td>(Above): Indoor view
(Below): Main gate</td><td>PVC(Polyvinyl Chloride)
Double window</td></tr>
</table>

3.3. GR Scope and Planning Direction of the Selected Building

Considering the utilization of the analysis results and the wide-ranging maintenance statuses of aged houses, the site and building type were based on the No. 4 case, but the aging performance of each item was analyzed as the aging performance with the highest ratio among the aging status survey results of the nine households. Table 5 (1) summarizes the average aging performance in terms of the building envelope (insulation, windows, doors), facility performance, indoor air quality, and user (elderly household) safety of the investigated buildings, (2) summarizes the problems in energy, air quality, and safety according to the aging performance of each item, and (3) explains the scope of improvement and method of remodeling for each item in terms of building envelope performance, interior and exterior finishing, facility performance, indoor air quality, and safety.

Table 5. Energy performance of aged houses, health problems of residents, and improvement directions according to the site survey.

Items	Location	(1) Average Performance Result from the Survey	(2) Health Issues of Occupants and Energy Consumption of Houses According to Respective Performances of Houses	(3) Targets for Improvement
Performance of building envelope	Insulation	None	Deteriorated indoor heating environment Caused dewing and appearance of mold Caused energy loss Caused health problems of aged people in winter	Exterior insulation (reinforcement of heat bridging performance): To improve indoor dewing and heating environment Works for improved air tightness of windows and window frames: to improve energy consumption Performance and heating environment Planning of windbreaker structure for frequently used doors
	Windows	Wood 3 mm and AL 3 mm		
	Air tightness	Frames of window became obsolete		
	Doors	No windbreak structure		
Interior and exterior finishing	Interior	Wallpaper	Mold appearing between wallpaper and furniture	Replacement with wallpaper with ecofriendly materials
	Exterior	Face brick and paint	Poor appearance of blushing and cracks	Improvement of finishing according to improved insulation
Equipment performance	Cooling	Air conditioner exclusively used for cooling	Caused by the consumption of more energy than actually required due to deteriorated performance of building	Replace with equipment of efficient energy consumption (Class I) to improve the performance of energy consumption
	Heating	Gas boiler		
	hot water supply			
Indoor air quality	Ventilation	None	Poorly ventilated fumes from cooking and micro-particulates that caused health problems in bronchus of mold	Installation of ventilator needs to be obligatory for households with aged people
Safety	Others	None	Convenience in use of toilet for aged people; handrails or emergency bells are not installed	Space planning without step Installation of handrails in toilet and emergency bells

4. Economic Analysis Considering Social Cost

4.1. Analytical Procedures and Methods

Regarding the analysis procedure and method, first, the energies before and after GR were analyzed by considering the spatial characteristics of the target building and the aging performances of the nine aged houses. The analysis tool was ECO-2, a Korean building energy efficiency rating program. For weather data of ECO-2, standard profiles were brought in from ECO-2 central server to allow selection of average data for 66 regions in Korea. Essentially, Korea has distinct climatic characteristics of four seasons: spring, summer, fall, and winter. Weather data of ECO-2 provide monthly average values calculated based on TMY (typical meteorological year data) weather data, which provides monthly average ambient temperature and monthly average solar intensity according to the incident angle by bearing. The target building of this study was located in Seoul. Accordingly, in ECO-2, Seoul was set out of 66 areas in Korea and analysis was conducted.

For the existing model (=building to be analyzed) and the improved model (=GR plan), the energy consumption was analyzed by preparing an improvement plan based on the aging performance and the renewal direction for each of items (1) and (3) in Figure 3 and Table 5. Second, the total construction cost was calculated per each item by dividing the aging performance (demolition cost, interior and exterior finishing, rest room renewal, etc.), health, safety, and energy performance of the improved model. Third, by comparing the energy and carbon generation of the existing model to the improved model in terms of ECO-2 analysis, the annual energy savings, greenhouse gas (CO_2) savings, and air pollutant savings were derived, then converted into costs to calculate the annual benefits. Next, by calculating the benefits ((1) energy saving cost (resident benefit—1), (2) greenhouse gas reduction (social cost—1) and (3) air pollutant reduction (social cost—2)) of the improved model compared to the total construction cost (cost), the economic feasibility was analyzed using the net present value method (NPV). Based on this, in the discussion section of Section 5, a GR support policy concept for low-income elderly households was proposed by mixing the 'housing stability policy for low-income elderly people' and the 'urban energy transition policy' of Korea Government. Figure 4 depicts a schematic diagram of the analysis procedure detailing each step and method of the target building (existing model).

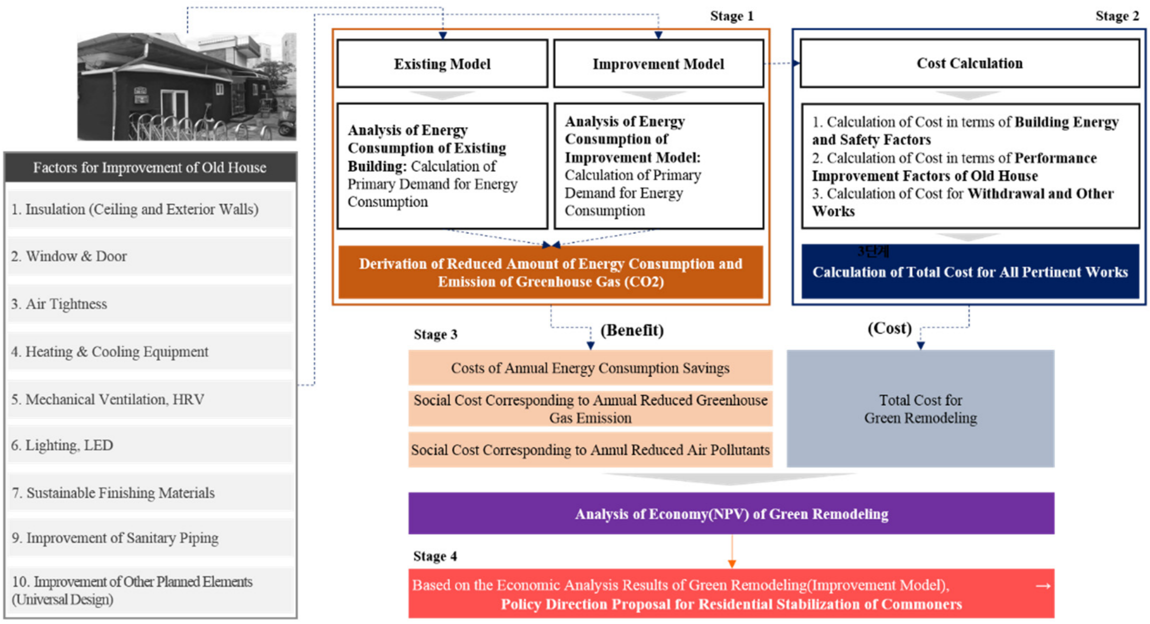


Figure 4. Problems considering elderly households in aged houses and improvement directions for each GR item.

4.2. Primary Energy Consumption Analysis for Existing and Improved Models

4.2.1. Primary Energy Consumption Analysis for Existing Model

As mentioned above, the primary energy consumption analysis for the existing model was conducted based on the architectural spatial properties (actual area and height) of the No. 4 case and the average aging performances of the nine aged houses. Tables 6 and 7 lists the key input values for energy performance analysis of the existing model as well as the reference notices and the energy performance result value output from ECO-2.

4.2.2. Improved Model Analysis

The energy performance of the improved model was set at the recommended level of the GR technical reference notices [41], and external insulation (adding 100 mm of mineral wool and dry finish) was applied for insulation remodeling in consideration of thermal bridge improvement and fire safety. Further, to improve the airtight performance, by applying a first-grade window set with airtight performance as well as applying airtight tape to the window frame (wall joint) and hole portions of the ventilation device, the building's airtight performance was analyzed by assuming grade 3 (based on ACH 50). Tables 8 and 9 shows the key input value for ECO-2 and the analysis results for the improved model.

4.2.3. Calculation of Annual Energy and Greenhouse Gas Reduction from the Energy Analysis Results

ECO-2 (Energy) Result Analysis: Comparison before to after GR

The heating energy requirement of the existing model was 173.9 kWh/m^2·y, and the heating energy requirement of the improved model was 60.4 kWh/m^2·y, which represents a reduction to 1/3 of the original value. In terms of cooling, it slightly increased from 31.4 kWh/m^2·y to 34.4 kWh/m^2·y. This is an analysis result that is generally acquired in residential buildings with improved insulation, as the heat exchange of the indoor heat generating load becomes difficult as the building's thermal insulation and airtight performance are improved.

The primary energy consumption of the existing model was the lowest grade (grade 7) for the building energy efficiency of 413.1 kWh/m^2·y, which indicated very poor energy performance. The primary energy consumption of the improved model was slightly lower than grade 3 for the building energy efficiency of 246.2 kWh/m^2·y, which was similar to the level of a newly constructed building. Improvements could be made to a higher level than this. However, as the level of improvement was judged to be appropriate in consideration of the construction cost, the current legal standards, and recommended standards of the Ministry of Land, Infrastructure and Transport, no additional energy performance improvement was conducted.

Comparison of Annual Energy Consumption and CO_2 Emission

The annual energy consumption and CO_2 emission were calculated based on ECO-2 analysis, and the energy consumption was calculated by converting it into the used amount of energy. It is necessary to understand the terms of primary energy consumption and the energy consumption. Energy consumption refers to the actual amount of energy required for equipment (cooling and heating equipment, hot water supply, ventilation and lighting equipment). The value calculated by converting the energy consumption into the primary energy is the primary energy consumption (= energy consumption × primary energy conversion factor for each source). Tables 10 and 11 present comparisons of the annual energy consumption and CO_2 emission for the existing model and the improved model, respectively.

Table 6. Key input values for 'ECO-2'—Existing model.

Items	Location	Investigation Results	Performance Corresponding to Survey Results	Sources and Assumptions
Usage	Usage profile	Residential space	-	Refer to [Attached Table 2] of the "Guidelines for Certification of the Class of Energy Consumption Efficiency of Buildings" [42]
Performance of building envelope	Exterior wall	Brick	0.611 ($W/m^2 \cdot K$)	Calculation of Thermal Transmittance: 1.0 B + EPS(Expanded Polystyrene) 50 mm + 0.5 B
	Ceiling	Shed roof	0.631 ($W/m^2 \cdot K$)	Calculation of Thermal Transmittance: Finishing + EPS(Expanded Polystyrene) 50 mm + Wood
	Windows	Wood 3 mm and AL 3 mm	4.0 ($W/m^2 \cdot K$)	Refer to [Attached Table 4] of the "Design Standards to Save the Energy Consumption in Buildings" [43]
	Doors	Ordinary door (of no windbreak structure)	2.70 ($W/m^2 \cdot K$)	
	Air tightness	Obsolete window frames	Six times (ACH50)	Educational Materials Prepared for the Program to Determine the Class of Energy Consumption Efficiency (In ECO-2, a domestic building energy evaluation program, for air tightness of residential buildings, ACH50 6.0 times is to be applied in the preliminary certification. Field measurement result is to be applied in the main certification. For this building, the preliminary certification standard was applied.)
Equipment performance	Cooling	PAC for exclusive cooling	(Cooling Capacity) 2.3 kW (Power Consumption) 0.67 kW	Performance of air conditioner installed at Household #4
	Heating Domestic hot water (DHW)	Gas boiler	(Heating Output) 24.4 kW (Thermal Efficiency) 83.4%	Performance of gas boiler for heating and hot water supply installed at the Household #4

Table 7. 'ECO-2' results of analysis—Existing model.

Category	Heating	Cooling	DHW	Lighting	Ventilation	Total
Energy Demand ($kWh/m^2 \cdot y$)	173.9	31.9	30.7	28.0	0	264.4
Energy Consumption ($kWh/m^2 \cdot y$)	379.5	8.3	36.8	28.0	0	452.6
Primary Energy Consumption ($kWh/m^2 \cdot y$)	425.6	22.9	40.6	76.9	0	566.0
CO_2 Emission ($kgCO_2$)	78.0	3.9	7.5	13.1	0	102.5
Primary Energy Consumption ($kWh/m^2 \cdot y$) for class	286.3	22.9	26.9	76.9	0	413.0

Table 8. Key input values for 'ECO-2′—Improved model.

Items	Location	Performance Improvement of Model	Details of Performance Improvement with Applied Materials	Remarks
Usage	Usage profile	Residential space	-	Equal to Table 8
Performance of building envelope	Insulation of exterior wall	0.23 (W/m^2·K)	Added with 100 mm of mineral wool (Dryvit)	Exterior insulation: minimization of costs for finishing and works against fire occurrence
	Insulation of floor	-	Added with the specially extruded heating plate (70 mm)	Preservation of heating energy and absorptivity of insulators were taken into account
	Insulation of ceiling	0.19 (W/m^2·K)	Added with 100 mm of rigid urethane foam	Application of inner insulation works by taking into account the Existing Framework
	Windows	1.41 (W/m^2·K)	PVC(Polyvinyl Chloride) and low-e double glazing duplicated window	Application of PVC(Polyvinyl Chloride) by taking into account the insulation and pertinent cost
	Doors	1.7 (W/m^2·K)	Insulated aluminum entrance door	Application of AL by taking into account of insulation and durability of entrance door
	Air tightness	Three times (ACH50)	Application of Airtight Tape to Windows and Parts joining with Doors	Materials for "air tightness" are applied to installation works for window frame and ventilator for three times (ACH50), the phrase of air tightness of ACH50 3.0 times that is generally applied after replacing windows in Korea is to be applied [10,44]
Equipment performance	Cooling	Replaced	(Capacity) 3.2 kW, (Power Consumption) 0.96 kW	A Product of Class I of the Energy Consumption Efficiency
	Heating / Hot water supply	Replaced	(Capacity) 13,000 Kcal, (Efficiency) 86.3%	A Product of Class I of the Energy Consumption Efficiency
	Ventilation	Additional equipment	(Capacity) 90 m^2/h, (Efficiency) Heating 71%, Cooling 56%	A Product Certified as the Equipment of High-efficiency in Energy Consumption

Table 9. 'ECO-2' results of analysis—Improved model.

Category	Heating	Cooling	DHW	Lighting	Ventilation	Total
Energy Demand (kWh/m^2·y)	60.4	34.4	30.7	19.1	0	144.5
Energy Consumption (kWh/m^2·y)	172.1	9.2	35.6	19.1	3.1	239.2
Primary Energy Consumption (kWh/m^2·y)	196.0	25.4	39.3	52.5	8.6	321.9
CO_2 Emission (kgCO_2)	35.8	4.3	7.2	9.0	1.5	57.8
Primary Energy Consumption (kWh/m^2·y) for class	133.5	25.4	26.1	52.5	8.6	246.2

Table 10. Comparison of annual energy consumption and savings.

Items	Annual Energy Consumption per Area	Area of Use	Annual Energy Consumption
Existing Model	452.6 kWh/m^2·y	28 m^2	12,672.8 kWh/y
Improvement Model	239.2 kWh/m^2·y	28 m^2	6697.6 kWh/y
Amount of Saving	-	-	5975.2 kWh/y
Rate of Saving (%)			47.2%

Table 11. Comparison of annual CO_2 emission.

Items	Annual CO_2 Emission per Area	Area of Use	Annual CO_2 Emission
Existing Model	106.3 kgCO_2/m^2·y	28 m^2	2976.4 kgCO_2/y
Improvement Model	57.8 kgCO_2/m^2·y	28 m^2	1618.4 kgCO_2/y
Amount of Saving	-	-	1358 kgCO_2/y
Rate of Saving (%)			45.7%

The energy consumption and CO_2 emission results in Tables 10 and 11 may have varied depending on the usage profile of ECO-2 (Regulations on Operation of Energy Efficiency Rating in Buildings, Annex 2) [42] and the actual building usage time and pattern, equipment efficiency, etc. However, ECO-2 is currently the only officially approved building energy performance evaluation tool in Korea, and it is generally used to estimate building energy performance and energy usage in the building planning stage and related research fields.

4.3. Calculation of Total Construction Cost (Cost) and Annual Benefit (Benefit) for Economic Analysis

4.3.1. Calculation of Total Construction Cost (Cost)

The calculation of the total construction cost of the improved model was entrusted to a construction cost expert. For the energy performance improvement, the performance level satisfying the "recommendation" of the GR technical reference [41] was applied. The mechanical equipment, the total heat exchange ventilation system (health improvement), and safety were separately quoted and applied. In addition, the aging performance improvement cost is the construction cost calculated based on the performance applied to a general house. The total construction cost came to about 20,000 USD; the construction cost per area is 714.2 USD/m^2. Considering that the new construction cost of an aged facility in Korea is 2100 USD/m^2 [45], it is possible to improve the energy performance of aged houses to the level of new constructions with a construction cost of about 33% compared to the cost of new construction.

Further, in the process of calculating the construction cost, it can be recognized that the energy performance and aging performance improvement should be carried out simultaneously instead of separately, while including the replacement of interior finishing (aging performance improvement) for window construction (energy performance improvement), and including the replacement of floor finishing for the improvement of floor heating, etc. This shows that the efficiency is high when the energy performance policy for aged houses and the housing stability policy for the people are implemented as a combined policy rather than as separate policies. Details of the total construction cost of the improved model are shown in Table 12 below.

Table 12. Calculation of construction cost for improved model.

No.	Location	Items	Area	Unit	Unit Cost (USD)	Total Cost (USD)	Remarks
1	Removal works	Interior removal, Waste disposal, Cleaning	28	m^2	35	980	Performance improvement of old house
2	Floor works	Water proofing, Panel heating, Specially extruded heating plate (70 mm)	27	m^2	45	1215	Improvement of energy consumption
3		Replacement of papered floor	28	m^2	25	700	Performance improvement of old house
4		Mop board (floor)	31	m	2.5	77.5	
5	Indoor walls	Finishing and papering of indoor walls	77	m^2	10,000	770	
6	Ceiling	Installation of wooden ceiling	27	m^2	15	405	
7		Gypsum boarding	27	m^2	7	189	
8		Papering	27	m^2	7	189	
9		Molding	35	m	4	140	
10		Ceiling insulation (rigid urethane foam 100 mm)	28	m^2	22	616	Performance improvement in energy consumption
11	Toilet	Replacement of tiles, Caulking, Water proofing	10	m^2	50	490	Performance improvement of old house
12		Toilet ceiling	2	m^2	60	120	
13		Washstand	1	ea	200	200	
14		Toilet bowl	1	ea	300	300	
15		Bath (shower) taps	1	ea	100	100	
16		Closet in toilet (for towels) including mirror	1	ea	300	300	
17		Hangers in toilet (towels and toilet papers)	1	ea	70	70	
18	Furniture	Installation of kitchen sink including taps	1	set	700	700	
19		Shoe closet	1	set	250	250	

Table 12. *Cont.*

No.	Location	Items	Area	Unit	Unit Cost (USD)	Total Cost (USD)	Remarks
20	Windows works	Replacement of inside doors	4	ea	250	1000	
21		Replacement of windows (PL window), Cracks	2	ea	350	700	Performance improvement in energy consumption
22		Ironware of windows for crime prevention	2	ea	150	300	
23		Replacement of entrance door and hardware	1	ea	550	550	
24	Miscellaneous works	Miscellaneous ironware (curtain box, floor frame)	1	sum	150	150	
25	Exterior works	Dryvit 100 mm (exterior wall)	72	m^2	70	5040	
26	Electrical works	Replacement of lighting (LED) of ceiling	3	ea	150	450	
27		Switches, socket outlets	1	sum	250	250	
28	Equipment	Installation of boiler and flue (Model: PRO135KS, N00)	1	sum	1000	1000	
29		Air conditioner on wall Attachment type (Model: SQ08S9JWAS, L00)	1	ea	1090	1090	
30		Total heat exchanging ventilator (Model: THE-80, L00)	1	ea	600	600	Health promotion (respiratory diseases, etc.)
31	Safety works	Emergency bells (living room 1, toilet 1) and in association with mobile phone	1	ea	380	380	Improvement in safety
32		Guide rails in toilet and living room	10	m	15	150	
33	Others	Other maintenance cost	1	sum	500	500	-
34	Overhead costs	Overhead cost for construction management	5	days	200	1000	
Sum of costs for works of improvement performance in health, safety and energy consumption (USD)					12,491		(59%)
Sum of costs of works for performance improvement of old facilities (USD)					8,490		(41%)
Total cost for all pertinent works (USD)					20,981		(100%)

4.3.2. Annual Benefit Calculation

Generally, social cost refers to the cost born from the activities of producers on the public and society as a whole. Social cost may include the external costs as a basic factor, and it may include or exclude private costs depending on the particular definition [46]. External costs are the costs incurred in removing public harms such as soot, odor, and noise. The external costs are not internalized by producers, but they are very important from a social point of view. As environmental problems grow, the importance of the external cost on social costs increases.

The social cost concept used in this study focused on external costs while excluding the private costs incurred from the generation of electricity. The external costs in terms of power generation can occur regardless of the size of the project, such as carbon emission reduction, air pollutant emission reduction, avoidance of distribution line construction cost, and avoidance of measuring cost [47]. However, it was excluded due to the limitation of social cost data, such as the avoidances of the distribution line construction cost and the measuring cost. Accordingly, the benefits of economic analysis considering the social cost in this study were set with the effects from (1) energy consumption cost reduction, (2) carbon emission reduction, and (3) air pollutant emission reduction.

Benefit from Annual Energy Saving

The annual energy cost savings were calculated by converting the annual energy consumption savings in Table 10 into costs. The annual electricity rate per kWh was calculated by applying 'the electricity rates for house in Korea (low voltage)' + '0.093 USD per kWh of electricity rate for the section below 300 kWh'. The calculation method is the same as that shown in Equation (1).

$$\text{Annual Energy Saving (USD/y)} = (\text{Energy Consumption } [(\text{kWh}/(\text{m}^2 \cdot \text{y})) \times \text{Area } (\text{m}^2)] \times \text{Electricity Rate (USD/kWh)} \tag{1}$$

Benefit from Annual Carbon Emission Reduction

The benefits of reducing carbon emissions are the social benefits resulting from the reduced consumption of electricity and energy.

The social benefits of the annual carbon emission (CO_2) reduction were calculated by converting the annual carbon savings in Table 11 into costs. To convert carbon emission reduction into cost, it was calculated by applying the average annual price of carbon credits in 2019 on the Korea Exchange (KAU 19), 22.8 USD per tCO_2. The calculation method is the same as that shown in Equation (2) [47].

$$\text{Benefit of annual carbon emission reduction (USD/y)} = (\text{Annual carbon emission reduction amount } [(\text{tCO}_2/(\text{m}^2 \cdot \text{y})) \times \text{Area } (\text{m}^2)] \times \text{Price of carbon credits } (\text{USD/tCO}_2) \tag{2}$$

Benefit from Annual Air Pollutant Material Reduction

The benefit of air pollutant material reduction is also a social benefit generated by the reduced consumption of electricity and energy. The calculation method is the same as that shown in Equation (3) [22]. The social cost of air pollutants was referred to as the social cost per MWh for nitrogen oxide, sulfur oxide, and dust by air pollutants in the preliminary feasibility report of "Smart Grid Expansion Project (2015)" of KDI. The benefit of nitrogen oxide was applied with 6.92 USD/MWh, that of sulfur oxide was applied with 3.97 USD/MWh, and that of dust was applied with 0.71 USD/MWh [47]. Table 13 provides the results of calculating the annual air pollutant reduction benefits according to the annual electricity savings.

$$\text{Annual air pollutant reduction benefit (USD/y)} = [(\text{Annual electricity savings (kWh/(m}^2\cdot\text{y))} \times \text{Area (m}^2)] \times \sum[(\text{Social cost of air pollutant (USD/kWh)}] \quad (3)$$

Table 13. Social cost according to the air pollutant reduction from the electricity saving.

Contents			Remarks
Annual amount of reduced energy consumption (MWh)		5975.2	Table 8 Results of analysis
Social cost corresponding to reduced emission of air pollutants	Nitrogen Oxides (USD/MWh)	6.92	[47]
	Sulfur Oxides (USD/MWh)	3.97	
	Dust (USD/MWh)	0.71	
Total benefit corresponding to annual amount of reduction of air pollutants (USD)		69.29	-

Table 14 shows the calculation of the total cost and benefit for economic analysis.

Table 14. Comparison of annual energy consumption and savings.

Items	Total Cost (USD)	Annual Amount of Total Benefit (USD)		
		Cost Corresponding to Reduced Annual Consumption of Energy	Social Cost Corresponding to Reduced Annual CO_2 Emission	Social Cost Corresponding to Reduced Emission of Air Pollutants
Total construction cost (Cost)	20,981.50	-	-	-
Annual amount of reduction cost (Benefit)		557.49	31.99	69.29

4.4. Economic Analysis Considering Social Cost

4.4.1. Economic Analysis Criteria

For economic analysis, the net present value (NPV) method was applied instead of the commonly used CBA (cost–benefit analysis). This was performed because the present value of future accrued benefits can be provided, and this can be used for other analyses in consideration of the analyzed net present value [24]. In addition, for the economic analysis criteria for public policies and buildings, the revision and supplementary studies of the general guidelines for conducting preliminary feasibility studies for public corporations and quasi-governmental institutions of the Korea Development Institute (KDI) were conducted while referring to [23]. The social discount rate was calculated as 4.5%, and the analysis period was set to 30 years, as was the case for building. The calculation method is the same as that shown in Equation (4). As a result of the analysis, when the net present value is greater than "0", it is judged to be economical. Here, Bt refers to the benefit of 't' period, Ct refers to the cost of 't' period, r refers to the social discount rate (interest rate), and t refers to the number of years of use.

$$\text{Net Present Value(NPV)} = \sum_{t=0}^{n} \frac{Bt}{(1+r)^t} - \sum_{t=0}^{n} \frac{Ct}{(1+r)^t} \quad (4)$$

4.4.2. Economic Analysis Result

As the result of the GR economic analysis of the aged house, the net present value was found to be "−10,267.15 USD (49.7%)", indicating that it is not economical, despite the effects of carbon reduction and air pollutant reduction applied. The amount of government support for the GR of low-income elderly households is not the total construction cost of "20,981.50 USD (100%)", but it may instead be estimated to be "10,267.15 USD (49.7%)" corresponding to the amount of support excluding residents net benefits (annual energy consumption reduction cost) and the social benefits from carbon and air pollutant reduction (see Table 15).

Table 15. Economic analysis result (net present value, NPV).

NPV	Total Cost (USD)	Total Benefit for Period of Operation (USD)		
		Cost Corresponding to Reduced Consumption of Energy (A)	Social Cost Corresponding to Reduced CO_2 Emission (B)	Social Cost Corresponding to Reduced Emission of Air Pollutants (C)
−10,267.15 (49% of Total Cost)	20,981.50 (100%)	9080.83 (43.2%)	504.85 (2.4%)	1128.67 (5.3%)
		10,714.35 (Sum of Benefit A, B, C; 51% of Total Cost)		

5. Discussion

According to the analysis results, among the total construction cost of GR, which has the effect of improving the health of residents of aged houses and reducing greenhouse emission, the ratio of construction cost for health, safety, and energy saving was 59%, and the ratio of construction cost for improving aging performance was 41%, as presented in Table 12.

From the 59% of health, safety, and energy saving construction cost, the energy saving cost incurred during the operation period is 43.2%, which is directly returned to the resident as a benefit generated while the resident continues to live in the property after GR. From the remaining 15.8%, 7.7% (2.4% + 5.3%) can be offset by the social benefits stemming from the carbon and air pollutant reduction effect according to the reduction in electricity consumption. That is, 15.8% of the actual cost is supported by the government for health, safety, and energy saving construction costs, but 7.7% is offset by the environmental improvement effect (effect of reducing carbon and air pollutants), so it can be estimated that only 8.1% would be supported. Seoul, Korea achieved a reduction of 4.7 million TOE of GHG emissions from December 2019 to April 2021 with the One Less Nuclear Power Plant Project, an energy transition policy [48]. Of the project budget, 89% was invested in the installation of new and renewable energy including solar power [49]. However, solar power is mainly installed in existing buildings, so there may be a difference between the installation efficiency of the system and the actual production efficiency due to climate influences such as surrounding buildings, maintenance, and the rainy seasons [50]. In areas with high building density, such as Seoul, there is a limitation to the quantitative expansion of energy conversion that can be achieved by installing solar power, so it is necessary to diversify the energy conversion policies rather than continuously increase the installation of solar power. As of 2021, 10 years have passed since this support policy was started, Seoul Metropolitan Government is still providing subsidies for solar power installation as part of the energy transition policy, which total 8.38 billion USD per year [48]. Some of this subsidy may be changed to support GR policy by linking it with energy conversion policy considering the energy saving effect (reduction of carbon and air pollutants) according to GR. Figure 5 presents the ratio of the energy saving construction cost support amount of GR as part of the energy conversion policy linked with the energy saving effect of GR.

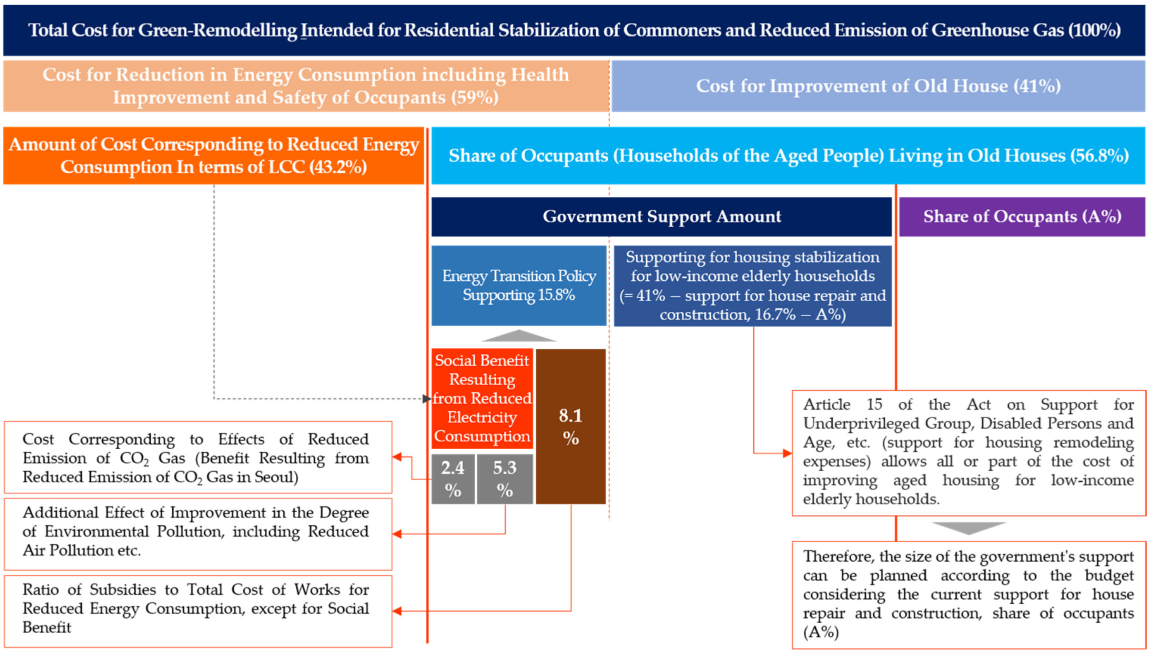


Figure 5. Concept of policy for supporting low-income housing stability from GR linked with the energy transition policy.

From the total construction cost of GR, the construction cost for aging performance improvement (41%) can be supported by the home repair and construction support policies for self-owned or rental households among low-income households with less than 60% of the median income in Seoul [51]. The scope of support is wallpaper, flooring, insulation, sanitary equipment (wash basin/toilet), lighting, etc., the scale of support is up to 1200 USD per household, and the support can reach up to 3200 USD by linking with the energy efficiency improvement project of the Korea Energy Foundation [52]. In addition, the Korean Government is subsidizing all or part of the cost of improving aged housing for low-income elderly households based on Article 15 of the Act on Support for Underprivileged Group, Disabled Persons and Age, etc. (support for housing remodeling expenses) [53]. From this study, the government can determine the amount of support by investigating the maximum payable dead amount to each households share amount (A%), calculating the "subsidy for the housing stabilization policy for elderly households (= 41%−(support for house repair and construction, 16.7%)−(resident share (A%)) by considering the size of the city and county unit budget secured, and establishing a plan to support each year depending on the number of supported households. Therefore, the size of the GR subsidy per households can be adjusted at a maximum of 24.4% of the total construction cost, according to the resident's share (A%).

Accordingly, it is possible to reduce the burden of construction cost for the GR implementation of low-income elderly households, and to increase the effect of improving facilities in aged houses from GR. It is expected that if the government utilizes the direct/indirect effects of GR, then the low-income elderly households can perform GR with support of a 1/4 of the GR construction cost, and the burden of the amount of support can be reduced as a result.

6. Conclusions

In this study, the economic feasibility of GR was analyzed while considering health, safety, and energy by investigating the status and characteristics of aged houses of low-income elderly people in Seoul. From the literature review, problems in the health, safety, and energy aspects of aged houses and architectural improvement directions were derived. Further, the aging status and energy performance of nine single-family and multi-family houses in which low-income elderly people in Seoul reside were investigated. A GR project was planned to improve health, safety, and energy performance by selecting one aged house where GR analysis was possible among the nine aged houses surveyed. Based on this plan, the total construction cost and energy performance before and after GR were analyzed, and the economic analysis was conducted in consideration of the social cost. As a result of the economic analysis of the GR for aged houses in which low-income elderly people live, the net present value was "−10,267.15 USD (49.7%)", indicating that there was no economic effect even though energy saving (9080.83 USD, 43.2%) as well as carbon (504.85 USD, 2.4%) and air pollutant reduction (1128.67 USD, 5.3%) effects were applied.

Nevertheless, from the analysis result, we propose a GR support plan linking with the current energy transition policies and the aged housing support policies for the low-income people, in an attempt to expand the GR of low-income people who are vulnerable to the health and safety of the aged houses and unable to implement GR. Of the total GR construction cost, the energy saving construction cost (59%) can be offset by 15.8% by linking with the energy transition support policy and by the energy consumption reduction amount of residents (43.2%). In addition, of the total construction cost of GR, the construction cost for improvement of aging performance (41%) was partially offset in Seoul by housing repair and construction support, and it was possible to secure a budget according to the Act on Support for Underprivileged Groups, Disabled Persons and Age, etc. of the Korean Government. Therefore, it is possible to calculate the subsidy for the housing stabilization policy for low-income households (=41%−support for house repair and construction, 16.7%−resident share, A%). Accordingly, it would be possible to establish policies at the city or county level to provide support each year according to the total supported households of low-income elderly people and the size of the budget secured.

Finally, in this study, the concept of a support policy was suggested through GR to improve old housing of small-scale low-income elderly people. However, this study has a limitation, in that the analysis was made only for detached houses. It is necessary to increase the reliability of the analysis result by increasing the number of buildings to be analyzed in the future. In addition, to improve housing of the poor, according to various housing types and ages in Korea, more diverse types of measures to improve housing for the general population are needed in the future. In the analysis process, ECO-2 was used to analyze the energy consumption of an aged house, but for the usage profile, the housing type of a general family, which is the default value of the program, is reflected, so it may differ from the housing patterns of elderly households and ordinary people. This value is the default value set by the government. Therefore, it is necessary to modify it or to revise the study so that more practical results can be derived by adding supplementary data.

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