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Analysis and Improvement of Building Energy Data Collection Systems for Green Remodeling of Aging Small Scale Residential Buildings in South Korea - Comparative Review of International and Domestic Practices

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Case Report

Keywords: Small-Scale Residential Building, Renewable Energy, Remodeling, GIS, Building Energy Data

Posted Date: November 6th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11427160/v1

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Additional Declarations: No competing interests reported.

Analysis and Improvement of Building Energy Data Collection Systems for Green Remodeling of Aging Small-Scale Residential Buildings in South Korea

Comparative Review of International and Domestic Practices

Abstract

This study aims to analyze domestic and international building energy data collection systems and propose strategies to promote renewable-energy-based green remodeling in aging small-scale residential buildings in South Korea. A five-step review of the literature and relevant documents was conducted to examine European policies and financial support mechanisms, hybrid geothermal–photovoltaic demonstration projects, and building energy data infrastructure. Domestic conditions were assessed by examining the green remodeling system established under the Green Building Construction Support Act, the policies and regulations of five metropolitan cities, and public data systems, including Seumteo, V-World, Architecture HUB, and the National Building Energy Database. Spatial information was also examined using geographic information systems (GIS). The comparison identified six structural problems: the absence of systematic data collection, a policy focus on public buildings, insufficient renewable energy data, inadequate integration of passive and active systems, limited economic feasibility, and a lack of post-retrofit performance verification. Six corresponding improvement strategies are proposed: mandatory monitoring, national demonstration programs, diversified financing mechanisms, one-stop service centers, integrated design guidelines, and phased regulatory mandates. Finally, the study highlights the need to establish an integrated, multilayered data structure at the building level.

Keywords: Small-Scale Residential Building, Renewable Energy, Remodeling, GIS, Building Energy Data

1. INTRODUCTION

Approximately 42.6% of all buildings in South Korea are at least 30 years old, and 78.4% are at least 10 years old(Kim et al., 2026; National Assembly Research Service, 2025). Residential buildings account for 46% of all existing buildings, and approximately 67% of residential buildings are at least 15 years old, making remodeling increasingly necessary(Jeong et al., 2024). In particular, as carbon neutrality has become a global priority in efforts to address the climate crisis, improving the energy performance of aging buildings through remodeling has emerged as a key strategy in the building sector(hereinafter referred to as “green remodeling”)(IEA, 2022). Accordingly, the government is pursuing a phased mandate for green remodeling, initially focusing on public buildings(Ministry of Land, Infrastructure, and Transport [MOLIT], 2024), while continuing to provide interest subsidies to encourage the adoption of green remodeling in the private sector(MOLIT, 2026). However, residential remodeling accounts for only approximately 3% of all building remodeling, while remodeling of multifamily housing including apartments, row houses, and multi-household houses accounts for only 0.5%(Park, 2024). Given the substantial proportion of residential buildings in the existing building stock, energy-saving measures in this sector offer considerable potential for reducing carbon emissions. Furthermore, generating renewable energy within buildings and on their sites provides an active means of offsetting carbon emissions. Promoting green remodeling, therefore, requires more than institutional and financial support; it also requires a supporting infrastructure that facilitates the technical and economic assessments necessary for implementation. Specifically, a robust data infrastructure is needed both to support policy-level decisions about which buildings to target and to inform and evaluate project-related decisions made by building owners, designers, and other stakeholders. For example, verifying the effectiveness of renewable-energy retrofits and assessing their economic feasibility require long-term life-cycle operational data documenting actual building performance before and after remodeling. However, data collection for remodeling projects incorporating renewable energy technologies, such as geothermal and solar power, remains extremely limited, particularly for small-scale residential buildings, including detached houses and row houses. Even the national integrated building energy database(DB) excludes detached houses and multifamily housing with fewer than 200 units from its coverage. Consequently, energy data for the largest segment of small-scale residential buildings are systematically missing(MOLIT, 2025; Korea Land and Housing Corporation, 2026). Surveys of household energy consumption behavior have also focused primarily on multifamily housing, leaving insufficient evidence for understanding the actual energy performance of small-scale residential buildings(Korea Energy Economics Institute, 2024). Without the systematic development and use of basic geographic information system(GIS)-based spatial data, it is extremely difficult to verify the effects of renewable-energy retrofits, optimize designs, and evaluate related policies. Currently, data relevant to policy decisions and project implementation for green remodeling are distributed across multiple systems. Moreover, information on small-scale residential buildings and their conditions before and after remodeling remains insufficient. Therefore, this study aims to analyze domestic and international data collection systems and propose improvement strategies for establishing and enhancing the data infrastructure needed to promote green remodeling in small-scale residential buildings.

The analytical scope of this study is limited to aging, small-scale residential buildings. Three criteria are used to define the target buildings: (1) the buildings must have received approval for use at least 30 years ago; (2) they must be used for residential purposes; and (3) they must be small-scale buildings. Buildings meeting all three criteria are included in the study.

The detailed criteria for building scale and structure are presented below.

Table 1. Selection Criteria for Target Buildings

Title	Scope
1. Use	Detached, multi
2. Scale	1-4 stories
3. Floor area	≤ approx. 660 ㎡ or small-scale criteria
4. Approval for use	≥ 30 years since approval for use
5. Structure	RC, masonry, light-gauge steel, etc.
6. Location	Dense aging low-rise residential areas
7. Remodeling	Renewable energy, envelope retrofit
8. Energy scope	Residential electricity

The study adopts a literature- and data-analysis approach. For international trends, it examines European policies and financial support mechanisms for residential remodeling, renewable-energy demonstration projects, and building energy data infrastructure. For the domestic analysis, it investigates the green remodeling framework established under the Green Buildings Construction Support Act, the policies and regulations of metropolitan local governments, and public data collection systems, including Seumteo, V-World, Building HUB, and the National Integrated Building Energy Database. Spatial information is examined using a GIS-based approach. On this basis, the study compares domestic and international practices in data collection and utilization to identify existing problems and propose improvement strategies. The research methodology comprises five main stages.

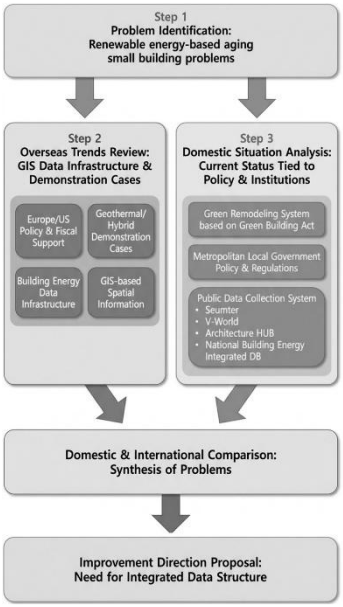


Fig. 1 Methodological Procedure of the Study(prepared by the author)

First, the study identifies the challenges associated with remodeling aging, small-scale residential buildings. Second, it reviews international GIS-based data infrastructure and renewable-energy demonstration projects to identify potential approaches to addressing these challenges. Third, it analyzes the domestic situation. Fourth, it synthesizes the identified problems by comparing domestic and international cases. Fifth, it proposes improvement strategies and explains the need for an integrated data structure to address the identified deficiencies.

2. INTERNATIONAL TRENDS IN RENEWABLE-ENERGY-BASED SOLUTIONS FOR SMALL-SCALE RESIDENTIAL BUILDINGS

Precedents in Europe and the United States demonstrate systematic efforts to improve the energy performance of aging residential buildings through policies and financial support implemented alongside the development of data infrastructure. However, this study focuses on European cases. Although European residential building types, such as detached and terraced houses(row houses), are comparable in scale and structure to detached houses, multi-household houses, and row houses in

South Korea, differences between the United States and South Korea even in detached housing in terms of lot sizes, insulation standards, and heating and cooling systems make direct comparisons difficult(Loga, Stein, & Diefenbach, 2016). Accordingly, this study examines European cases in which policy measures and financial support have been systematically developed alongside building energy data infrastructure. This section examines four main areas to identify potential approaches to improving domestic practices: (1) the evolution of remodeling technologies; (2) policy and financial support strategies in major countries; (3) demonstration projects involving hybrid renewable energy systems; and (4) data infrastructure and evaluation tools. These areas are reviewed sequentially and then considered collectively.

(1) Evolution of Remodeling Technologies for Aging Small-Scale Residential Buildings

Renewable energy technologies applicable to aging, small-scale residential buildings can be classified into two main categories: electricity generation and thermal energy supply for space heating, cooling, and domestic hot water. Each technology requires specific site conditions and input data for effective implementation. Photovoltaic(PV) systems primarily depend on solar irradiance and the available installation area on roofs and façades, whereas solar thermal systems are designed primarily to meet domestic hot water demand and depend on available solar radiation. Air-source heat pumps (ASHPs) rely on outdoor ambient conditions and the characteristics of existing heating systems, whereas ground-source heat pumps(GSHPs) depend on site availability and ground thermal conductivity. Biomass systems, in turn, require consideration of fuel availability and supply conditions, as well as exhaust requirements. In Europe, hybrid systems combining GSHPs with solar PV, solar thermal collectors, or photovoltaic-thermal(PV-T) systems are becoming increasingly widespread as a means of meeting heating and cooling demands efficiently. Furthermore, GSHPs have been identified as economically efficient options for renewable heating and cooling because of their potential applicability across a range of small-scale residential building types and sizes(Reinhardt et al., 2024).

Table 2. Renewable Energy Technologies for Small-Scale Residential Buildings

Technology	Type	Variables
1. PV	Electricity	Roof/façade area, solar irradiance, etc.
2. Solar thermal	Heat(heating)	Solar irradiance, DHW
3. AHSP	Heat(cooling, heating)	Outdoor temperature, existing heating system
4. GSHP	Heat(cooling, heating)	Site area, ground thermal conductivity
5. Biomass	Heat(heating)	exhaust conditions

A brief overview of these technologies highlights the following characteristics:

1. Photovoltaic(PV) panels: These systems are relatively easy to install on rooftops and can also be integrated into building envelopes through building-integrated photovoltaics (BIPV).
2. Solar thermal panels: These systems can effectively supplement domestic hot water production but generally require an auxiliary heat source.
3. Air-source heat pumps(ASHPs): These systems have relatively low installation costs and are straightforward to implement, although their efficiency can decrease in cold-climate zones.
4. Ground-source heat pumps(GSHPs): These systems offer high energy efficiency but are constrained by site conditions and the requirements for ground drilling.
5. Biomass systems: These systems are particularly suitable for rural areas and locations without access to natural gas distribution networks.

(2) Policy and Financial Support Trends in Major European Countries

In October 2020, the European Union(EU) announced the Renovation Wave initiative, identifying three priority areas: improving energy affordability for low-income households, promoting the energy-efficient renovation of public buildings, and decarbonizing heating and cooling systems. The initiative aims to double the rate of building renovation(Beltrán-Velamazán et al., 2024). The revised Energy Performance of Buildings Directive(EPBD 2024/1275) establishes zero-emission building standards for all new buildings beginning in 2030. It also introduces mandatory National Building Renovation Plans (NBRPs), Building Renovation Passports(BRPs), and a Smart Readiness Indicator(SRI) assessment framework for existing buildings(Vences, 2026; Gouveia et al., 2025; Chatzikonstantinidis et al., 2025). The EU estimated that approximately €275 billion in additional annual investment would be required to achieve its 2030 carbon reduction targets, identifying a funding gap of €127 billion relative to the 2023 investment level of €73 billion. Furthermore, member states are required to establish national targets for renovating 5% of their building stock annually. These measures underscore the importance of one-stop shops and district-scale renovation approaches(Bertoldi et al., 2025; Bürger et al., 2026). Collectively, these initiatives establish an integrated virtuous cycle.

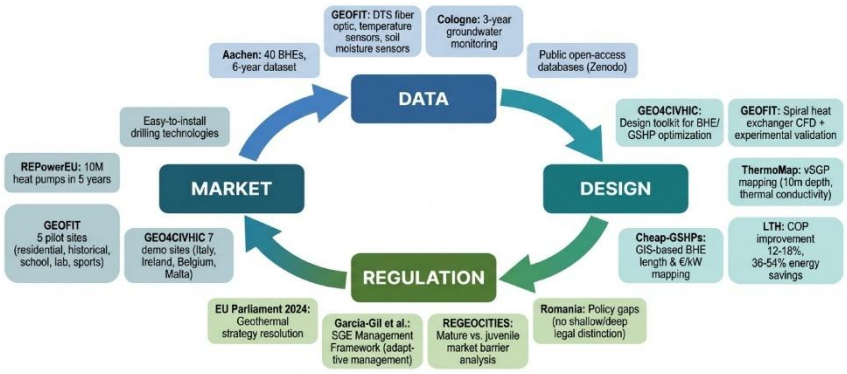


Fig. 2 EU's Virtuous Cycle for Addressing Data Gaps(García-Gil et al., 2020)

Financial and fiscal support mechanisms vary across European countries. An examination of representative national approaches reveals the following characteristics:

1. Germany: Building owners can choose between debt relief and cash subsidies based on a building's energy efficiency rating. The country also offers reduced loan interest rates of 1% per building, supporting an annual green renovation rate of 2%. In addition, newly installed heating systems must use at least 65% renewable energy(IEA, 2025).
2. Italy: The Superbonus 110% program provides tax credits of up to 110% of eligible home energy-efficiency improvement costs over five years. Because these credits can be transferred to third parties, including construction contractors and financial intermediaries, building owners with little or no initial capital can more readily undertake renovation projects.
3. The Netherlands: The Energy Investment Allowance(EIA) provides tax incentives for green renovation investments, supporting expenditures ranging from €2,500 to €126 million.
4. France: Government-certified environmental professionals, designated RGE(Reconnu Garant de l'Environnement), provide advisory and administrative services. Subsidies are tiered according to household income(Bürger et al., 2026).
5. The United Kingdom: The Boiler Upgrade Scheme(BUS) provides grants of £7,500 to replace fossil fuel boilers in existing buildings with air-source or ground-source heat pumps(Ofgem, 2025).

Overall, the EU's REPowerEU plan aims to support the installation of 10 million additional heat pumps over five years, with small-scale heat pumps accounting for 20% of total installations(Fedrizzi, 2023).

Table 3. Renewable Energy Remodeling Policies for Residential Buildings

Country	Key Scheme	Main Content
1. France	RGE	Certified expert consultation + income-based subsidies
2. UK	BUS	£7,500 for air/ground source heat pumps(existing buildings)
3. Italy	Super Bonus	Up to 110% tax credit(5 years), transferable to third parties
4. Netherlands	EIA	Reduced tax on green remodeling costs(€2,500 - €126 million)

(3) Hybrid Renewable Energy Retrofits in Aging Residential Buildings

In Europe, renewable energy retrofits are supported not only through policy frameworks but also through demonstration projects and systematic data collection. The EU-funded GEO4CIVHIC project promotes the installation of compact geothermal systems in existing and historic buildings. It has developed modular units tailored to small-scale residential building types, including detached and terraced houses. Within this project, ground-source heat pumps(GSHPs) are combined with solar photovoltaic(PV) and solar thermal systems in hybrid configurations to meet heating and cooling demands. Solar PV systems installed at optimal tilt angles have demonstrated self-sufficiency rates of up to 40%, even in cold climates (Geo4Civhic et al., 2023). In Germany, demonstration projects involving centralized and decentralized geothermal heat pump systems are being conducted in existing urban districts(Krause et al., 2025). A case study of a detached house in Hamburg found that a solar-geothermal hybrid system achieved the shortest payback period, ranging from 5 to 10 years(Hu et al., 2024). Similarly, a study of a detached house built in Finland in 1954 identified a combination of exterior insulation, a GSHP, and solar PV panels as the optimal energy-saving strategy, reducing final energy consumption by approximately 76% (Järvistö, 2023).

Table 4. Renewable Energy Remodeling Cases in Europe

Case	Target	Outcome
1. Germany	PV-geothermal hybrid for detached houses	Payback period 5-10 years(shortest)
2. Finland	External insulation + GSHP + PV	Approx. 76% reduction in final energy
3. UK	GSHP	16,117 → 4,560 kWh, COP 3.3, carbon payback approx. 5 years
4. Spain	5-year continuous monitoring with 82 sensors	Pre/post-retrofit performance quantified via KPIs(e.g., HTC)

An analysis of international trends reveals four major findings.

1. Expansion of Hybrid Systems: Renewable energy retrofits are evolving beyond standalone solar photovoltaic(PV) installations toward hybrid systems integrating geothermal and solar energy. Solar-geothermal configurations have emerged as a key strategy because of their relatively short payback periods and potential for substantial cost savings.
2. Integration of Policy Measures and Financial Incentives: European countries are promoting the renovation of small-scale residential properties, where decisions typically depend on individual homeowners, by combining diverse financial instruments including interest-free or low-interest loans, transferable tax credits, and income-based subsidies with streamlined implementation services through one-stop shops.
3. Data-Driven Performance Verification: Requirements and initiatives involving building energy storage systems, continuous real-time monitoring, and key performance indicator(KPI) based evaluations support the systematic collection and verification of baseline data and post-retrofit performance data.
4. Refinement of Assessment Scale and Scope: Tools for evaluating renewable energy potential and economic feasibility are expanding beyond solar energy to include geothermal energy. At the same time, the spatial resolution of these tools is becoming increasingly detailed, enabling assessments at the individual-building level.

Taken together, these international trends indicate that policy and financial support mechanisms are advancing alongside the development of robust building energy data infrastructure.

3. ANALYSIS OF THE DOMESTIC CONDITIONS OF AGING SMALL-SCALE RESIDENTIAL BUILDINGS

Unlike international cases, in which renewable-energy-based remodeling has been developed alongside data infrastructure and diverse policy and financial support mechanisms, green remodeling in South Korea remains primarily focused on public buildings at the policy level. Insufficient public–private collaboration has also resulted in a structural limitation: the lack of adequate data collection infrastructure. Accordingly, this chapter examines four major issues. The first concerns the institutional foundations and policy limitations of South Korea's Green Remodeling Program. The second involves regional differences in the policies and regulations implemented by metropolitan and provincial governments. The third concerns the adoption of renewable energy technologies in small-scale residential buildings and the lack of fundamental data. The fourth involves the fragmented nature of remodeling efforts, particularly those focused on window replacement. For aging, low-rise residential buildings, such as detached houses and multi-household houses, which are the primary focus of this review, various approaches to developing project platforms are also being explored in connection with redevelopment and reconstruction initiatives.



Fig. 3 Aging Low-Rise Residential Areas(Realcast; Hana Bank, 2022).

(1) Problem 1: Green Remodeling Systems and Policies

In South Korea, green remodeling has been promoted since 2014 under Article 27 of the Green Building Construction Support Act. Public building projects provide subsidies for construction costs associated with facilities such as senior centers, public health centers, and daycare centers that are at least 10 years old, provided that at least two energy performance improvement measures are implemented. By the end of 2024, a cumulative total of 3,590 buildings had undergone retrofits,

with approximately KRW 926.8 billion in funding disbursed(National Assembly Research Service, 2025).

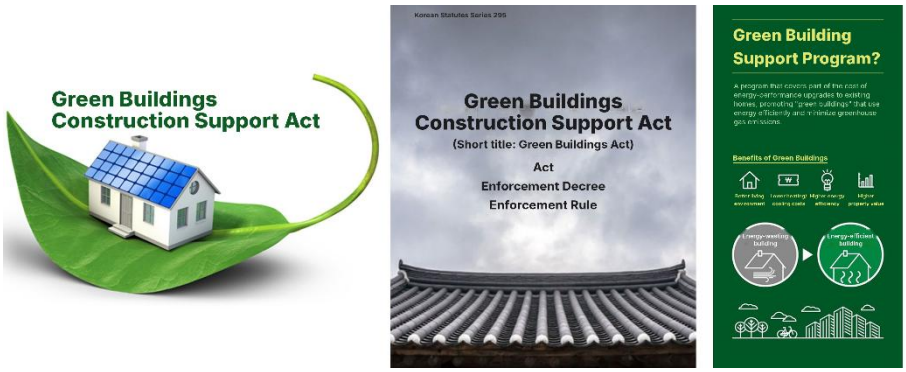


Fig. 4 Green Building Construction Support Act(Korea Law Information Center, 2025).

The nationwide regulatory framework comprises three main components. First, the Zero Energy Building(ZEB) Certification Standards, implemented on January 1, 2025, provide a basis for establishing building performance targets and assessing certification feasibility. Second, the Energy Conservation Plan system determines whether buildings are subject to relevant permitting requirements. Third, the New and Renewable Energy Housing Support Program, administered by the New and Renewable Energy Center of the Korea Energy Agency, provides a framework for determining eligibility for subsidies and other forms of support.

Table 5. Regulatory Framework and Its Application

Category	Target	Outcome
1. Green Building Construction Support Act	PV-geothermal hybrid for detached houses	Payback period 5-10 years(shortest)
2. Energy Saving Plan	Required for building permits or change of use above a certain scale	Review of whether remodeling requires a permit
3. ZEB Certification	ZEB certification criteria effective from Jan. 1, 2025	Assessment of performance targets and certification feasibility
4. Renewable Energy Housing Support Program	Support for installing renewable energy systems in housing	Assessment of subsidy/support eligibility
5. Major Repair, Extension, and Change of Use under the Building Act	Permit or report required depending on scope of work	Classification into repair, major repair, or extension

Among these nationwide policies, the ZEB certification roadmap, fully implemented in 2025, aims to strengthen renewable energy installation requirements and establish future building performance targets. Consequently, financial and tariff-related support mechanisms, including direct subsidies and interest subsidies, are key factors in evaluating policy effectiveness. However, since the private building green remodeling interest subsidy program was introduced in 2014, it has supported only 640 detached houses and 102 nonresidential buildings over a 10-year period. New applications were suspended in November 2023 because of limited program uptake amid high interest rates(National Assembly Research Service, 2025). Although privately owned buildings account for approximately 96% of all buildings, practical support remains largely concentrated on public buildings. Furthermore, research on public building retrofits has focused heavily on specific facility types, including daycare centers, public health centers, and fire stations(Cho et al., 2023; Bang et al., 2024; Kim et al., 2025; Lee et al., 2025).

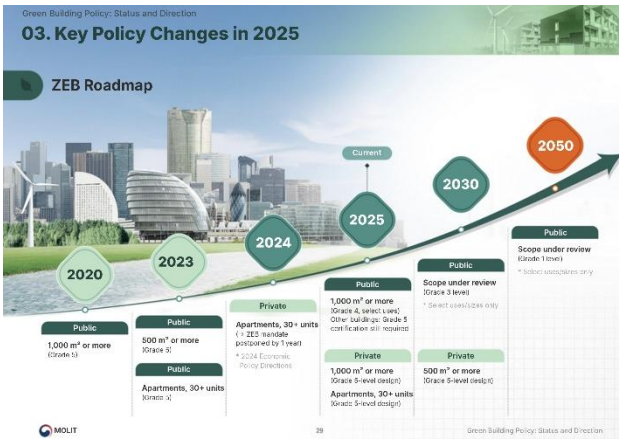


Fig. 5 Example of the Policy and Regulatory Data Layer(Korea Energy Agency, 2025).

Focus group interviews(FGIs) with field experts have consistently highlighted the need for institutional improvements (Woo & Lee, 2023). In addition, economic feasibility analyses have found that, under the existing policy framework, the net present value(NPV) can be as low as - KRW 79.64 million, indicating substantial economic challenges to achieving the 2030 carbon reduction targets and 2050 carbon neutrality goals(An et al., 2023).

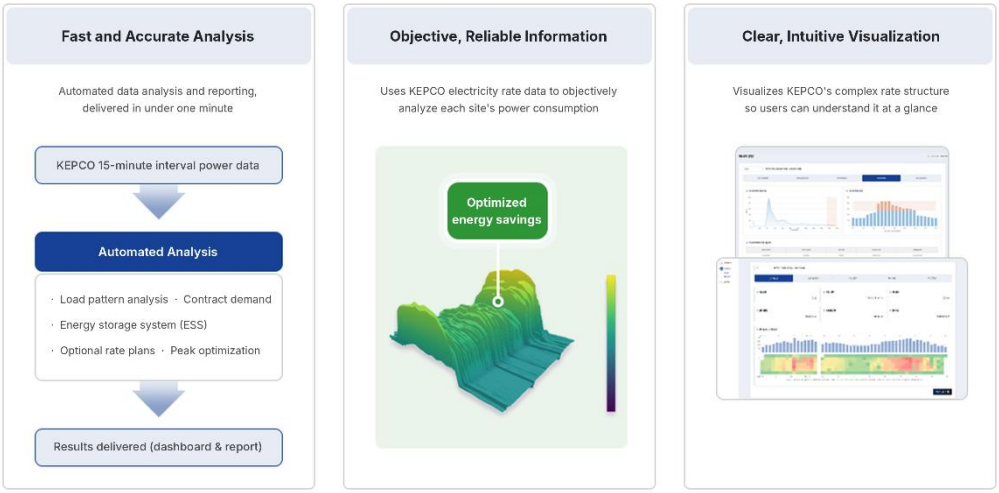


Fig. 6 Example of the Cost and Tariff Data Layer(Ministry of Land, Infrastructure, and Transport, 2025).

In addition to these nationwide institutional limitations, differences in regional government regulations introduce further variables that affect the implementation of green remodeling projects.

(2) Problem 2: Regional Disparities in Metropolitan Government Policies and Regulations

Although nationwide standards provide a common regulatory framework, their practical application varies according to the design criteria, local ordinances, and support programs established by metropolitan governments. Seoul, for example, operates the Building Retrofit Project(BRP), which provides loans primarily to privately owned buildings that have been in use for at least 15 years. Other metropolitan cities have distinct characteristics that influence their remodeling policies and implementation requirements. Busan, a densely developed coastal city, faces challenges associated with strong winds and shading in sloped areas. Incheon is influenced by airport-related height restrictions, landscape requirements, and district-unit planning regulations in its Free Economic Zones. Daegu's priorities are shaped by heatwaves and cooling demand, whereas Gwangju focuses primarily on integrating remodeling with urban regeneration. Daejeon places particular emphasis on privately owned buildings, while Ulsan addresses environmental considerations associated with its industrial and coastal settings.

Table 6. Region-Specific Policy and Regulatory Categories

City	Key Region Specific Category
Seoul	BRP loan support, sunlight/shading in dense low-rise residential areas, installation restrictions in historic and cultural environments
Busan	Coastal strong winds/typhoons, shading on slopes and hillside roads (Sanbok-doro), adjustment of installable area
Incheon	Airport height restrictions, coastal salt damage, district unit plans in free economic zones, island accessibility
Daegu	Heat waves and basin climate, high cooling loads, integration of windows/insulation/solar shading with PV
Gwangju	Regeneration of aging residential areas(linked to urban regeneration), linkage with policy programs and subsidies
Daejeon	Green building design standards for private buildings, linkage with research- and administration-oriented demonstration projects
Ulsan	Environmental correction for residential areas adjacent to industrial zones, maintenance costs for coastal salt damage and strong winds

A detailed analysis was conducted for five metropolitan cities Seoul, Busan, Incheon, Daegu, and Gwangju for which policy information and data were relatively accessible. Daejeon and Ulsan are discussed more briefly, with emphasis on their region-specific considerations. Consequently, even when similar renewable energy remodeling technologies are applied, implementation requirements vary according to each city's climate, industrial characteristics, and spatial structure. These differences complicate standardization because the coefficients and parameters used in basic spatial data may need to reflect regional conditions.

① Seoul: BRP Loan Support and Solar Access and Shading Regulations

Seoul implements the Seoul Green Building Design Standards, which took effect on January 2, 2025. The city is also a representative example of a local government operating the Building Retrofit Project(BRP), which provides low-interest loans for privately owned buildings that have been in use for at least 15 years. For residential buildings, eligibility is restricted to those with an officially assessed value of KRW 1.2 billion or less. These measures reflect the structural characteristics of Seoul, where the building sector accounts for approximately 70.7% of total carbon emissions.

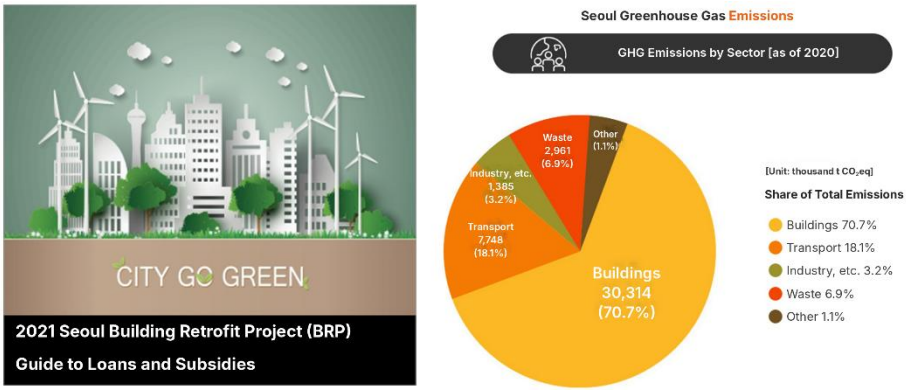


Fig. 7 Carbon Emissions by Sector(Seoul Metropolitan Government, 2026).

The BRP provides comprehensive support for energy efficiency improvements, including the replacement of insulated windows, the installation of high-efficiency lighting, upgrades to heating, ventilation, and air-conditioning(HVAC) systems, and the installation of renewable energy facilities.



After Construction **Before Construction**

Fig. 8 Example of a Building Renovated under Seoul's BRP Support Program

Seoul aims to promote an integrated approach that combines passive and active design strategies. This approach expands the scope of the BRP beyond conventional measures that minimize energy consumption through passive design to include active strategies that reduce reliance on external energy supplies through on-site energy generation.

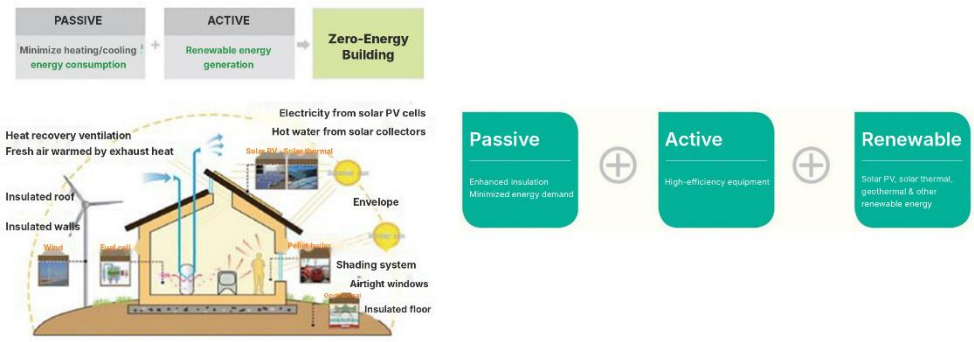


Fig. 9 Concept of Integrated Passive and Active Design for Zero Energy Buildings (ZEBs)(Seoul, 2026).

This approach is reflected in the vision of "Seoul-Style Green Building for People, Environment, and Future" and the goal of establishing a foundation for carbon neutrality by 2050. Within this framework, Seoul identifies several key factors for consideration when developing a green remodeling support platform. These include reducing initial cost burdens through BRP loan support; addressing solar access and shading constraints in high-density, low-rise residential areas; accounting for installation restrictions or additional review requirements in historically and culturally significant areas; and considering the risk of prolonged investment recovery periods in neighborhoods designated for redevelopment or reconstruction.

Table 7. Seoul-Specific Factors and Their Implications for Platform Development

Specific Factor	Application
1. BRP loan support	Calculation of reduced initial cost burden
2, Green building design standards	Review of permits and standards
3, Historic and cultural environment	Warning of installation restrictions or additional review
4. Low-rise residential buildings	Enhanced sunlight and shading analysis
5. Redevelopment/reconstruction zones	Indication of long-term investment recovery risk

② Busan: Structural Safety and Installation Standards for Coastal Salt Exposure and Strong Winds

Busan implemented revisions to its Busan Green Building Design Standards on July 1, 2024, to promote energy-efficient building design, encourage the installation of renewable energy facilities, expand green building certification, and foster a carbon-neutral built environment.



Fig. 10 Busan's Vision and Strategy (Busan, 2026).

As a densely populated coastal city in South Korea, Busan has extensive areas of deteriorating low-rise and hillside residential buildings. Concentrations of aging single-family and multifamily housing are found along Sanbokdoro(hillside ring roads) and in coastal areas. These buildings present persistent challenges associated with low energy efficiency.



Fig. 11 Low-Rise and Hillside Residential Areas in Busan, Including Jurye Railway Village and Gamcheon Taegeukchon(Busan, 2026).

Unlike inland cities, Busan's coastal environment is characterized by strong sea breezes, high wind speeds, and elevated humidity. These conditions create distinctive building maintenance requirements and necessitate site-specific environmental

assessments when renewable energy retrofits are implemented. Under its “Clean Energy City Busan” vision, the city identifies several critical considerations for integrating renewable energy systems into aging residential buildings. These include accounting for the maintenance costs of photovoltaic systems exposed to marine salt damage, evaluating structural safety under strong winds and typhoon conditions, improving solar irradiance and shading assessments for hillside residential buildings, and adjusting allowable installation areas in Sanbokdoro residential districts.

Table 8. Busan-Specific Factors and Their Implications for Platform Development

Specific Factor	Application
1. Coastal salt damage	Consideration of PV maintenance costs
2, Strong winds and typhoons	Warning for structural safety review
3, Hillside residential areas	Enhanced solar irradiance and shading analysis
4. Hillside road residential areas	Adjustment of installable area

③ Incheon: Tiered Regulations for Airport Vicinity Areas and Free Economic Zones

On May 19, 2025, Incheon issued a public notice concerning partial revisions to the Incheon Green Building Design Standards. The city has a complex urban structure in which coastal areas, seaports, international airports, islands, and Free Economic Zones(FEZs) coexist. The spatial proximity of FEZs, port hinterlands, and aging residential buildings in older urban districts creates architectural, environmental, and regulatory conditions that differ from those in inland cities. Consequently, marine salt exposure, airport-related height restrictions, industrial microenvironments near ports, and district-unit plans within FEZs directly affect the feasibility of renewable energy retrofits.



Fig. 12 Incheon’s City Brand and Urban Landscape(Incheon, 2025).

Incheon classifies buildings into four categories(Groups A-D), each subject to different regulatory standards. For Group D, which covers the smallest buildings, the standards recommend achieving at least Grade 4 under the Green Building Certification system and Grade 2 or higher under the Energy Efficiency Rating system. They also recommend installing high-efficiency equipment, including environmentally friendly boilers, mechanical ventilation systems, and LED lighting. In addition, the minimum required renewable energy installation ratio for privately owned residential buildings, starting at 7%, is scheduled to increase every two years, reaching 12%-14% by 2030.

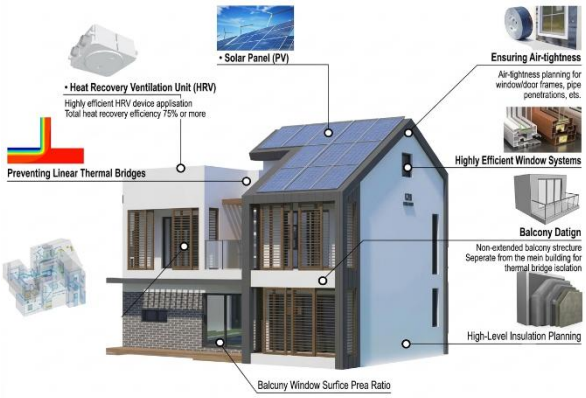


Fig. 13 Conceptual Diagram of Incheon’s Carbon-Neutral Green Building Design Standards

In this context, Incheon identifies several key considerations for integrating renewable energy systems into building

renovation projects. These include reviewing installation height restrictions associated with airport proximity, adjusting equipment service-life and maintenance cost estimates to account for marine salt exposure in coastal areas, examining applicable district-unit plans within FEZs, and accounting for construction costs and maintenance accessibility in island regions.

Table 9. Incheon-Specific Factors and Their Implications for Platform Development

Specific Factor	Application
1. Airport height restrictions	Review of structure installation height
2. Coastal salt damage	Consideration of equipment lifespan and maintenance costs
3. Free economic zones	Review of district unit plans
4. Island areas	Construction costs and maintenance accessibility

④ Daegu and Gwangju: Heatwave Adaptation and Integration with Urban Regeneration

Daegu seeks to develop a sustainable green city and reduce carbon emissions through its Daegu Ordinance on Support for the Creation of Green Buildings and the associated design standards. As an inland basin city, Daegu faces substantial cooling demands during summer heatwaves, making heat-related performance requirements a critical consideration in building design and renovation.



Fig. 14 Green Building Design Standards in Daegu and Gwangju

Daegu considers not only solar PV generation potential but also the potential for reducing cooling costs through improvements in insulation, thermal barriers, and windows. Key considerations for integrating these factors into a remodeling support platform include strengthening cooling energy reduction strategies suited to the city's heatwave-prone basin microclimate, developing remodeling scenarios specifically addressing window replacement and building envelope insulation, improving the thermal performance of aging low-rise residential buildings, and incorporating an integrated calculation framework that accounts for both solar power generation and cooling cost savings.

Table 10. Daegu-Specific Factors and Their Implications for Platform Development

Specific Factor	Application
1. Heat waves and basin	Enhanced cooling energy savings effect
2. Summer cooling load	Consideration of windows and insulation
3. Aging low-rise residential buildings	Envelope-focused performance improvement
4. Solar utilization potential	Integration of PV generation and cooling cost savings

Gwangju seeks to improve building energy efficiency and reduce carbon emissions through the Gwangju Metropolitan City Ordinance on Support for the Creation of Green Buildings. As of the study period, the city was conducting research related to the development of its Third Green Building Action Plan for 2026. Gwangju has also linked the regeneration of aging residential districts with the identification of priority areas for building retrofits. Its approach incorporates assessments of the economic feasibility of photovoltaic systems based on solar irradiance, relevant policy initiatives, subsidies linked to urban regeneration, and analyses of the energy-saving effects of improvements to insulation, windows, and building envelopes.

Table 11. Gwangju-Specific Factors and Their Implications for Platform Development

Specific Factor	Application
1. Aging residential buildings	Identification of priority remodeling sites
2. PV potential	Irradiance-based PV economic feasibility assessment
3. Urban regeneration linkage	Linkage with policy programs and subsidies
4. Energy performance improvement	Effects of insulation, windows, and envelope retrofitI

⑤ Synthesis of the Five Cities: Applicability of Policies and Regulations

The five metropolitan cities examined Seoul, Busan, Incheon, Daegu, and Gwangju share a common legal hierarchy comprising three levels: the national Green Building Construction Support Act, municipal Green Building Construction Support Ordinances enacted by local governments, and city-specific Green Building Design Standards. This framework can be evaluated sequentially, beginning with legal applicability at the municipal level, followed by an assessment of policy and institutional support, and concluding with economic recalculations.



Fig. 15 Common Legal Framework Applicable to the Five Cities

When incorporated into the proposed platform, this framework must accommodate city-specific variations by organizing relevant parameters into four components: (1) common legal requirements; (2) differentiated legal and policy provisions; (3) characteristics of renewable-energy-based upgrades in aging residential neighborhoods; and (4) platform-specific integration criteria.

Based on these components, an eight-stage checklist is proposed for city-specific implementation:

1. Classify residential buildings: Identify residential buildings that are at least 30 years old, measured from the date of approval for use. This criterion is common to all seven cities discussed in the study.
2. Determine the scope of work: Classify the proposed intervention as a minor repair, major repair, expansion, or change of use.
3. Check municipal ordinances: Determine whether the relevant Green Building Construction Support Ordinance applies.
4. Check city-specific design standards: Determine whether the applicable Green Building Design Standards impose additional requirements.
5. Assess renewable energy integration: Evaluate the feasibility of incorporating renewable energy systems.
6. Review region-specific regulatory constraints: Examine local restrictions, particularly those associated with Seoul, Busan, and Incheon.
7. Account for local environmental conditions: Consider microclimatic and other environmental factors that may affect system performance and installation feasibility.
8. Integrate financial support: Identify applicable subsidies, loans, and other financial support programs, prioritizing cities with verifiable policy initiatives, such as Seoul and Gwangju.

Table 12. Step-by-Step Integrated Framework for Policy and Regulatory Analysis

Step	Content	Data Used	Laws
1. Building	Analysis target	Coordinates, building/address ID, etc.	Building Act
2. Building register	Use, number of floors, floor area, approval date	Seumteo, building register, etc.	Building Act, Building Management Act
3. Location	Zoning, district unit plans, landscape	V-World, National Geographic Information Platform, continuous digital topographic maps, etc.	National Land Planning and Utilization Act, municipal urban planning ordinances
4. PV installable area	Roof area, orientation, slope analysis	3D building models, DEM, aerial photos, etc.	Building Act, building structural standards
5. Irradiance and shading	PV efficiency and shading effects	KMA solar irradiance data	Green building design standards,

			sunlight right standards
6. Expected generation	Annual generation and self-consumption	Irradiance data, PV modules, etc.	Renewable Energy Act
7. Initial installation cost	Construction costs for PV, windows, and insulation	Standard cost estimates, construction cost DB	Construction cost standards, standard cost estimates
8. Loans and subsidies	National/local subsidies and loans	Korea Energy Agency, local government support programs	Renewable Energy Housing Support Program, local ordinances
9. Electricity cost savings	Electricity bill savings	KEPCO electricity tariffs	Electricity Business Act, KEPCO tariff system
10. Payback period	Investment payback period	Maintenance costs, generation, savings	Life cycle cost standards

In conclusion, the policy and regulatory hierarchy serves not merely as a mechanism for reviewing legal requirements but also as a critical filter that determines the practical feasibility and economic parameters of renewable energy retrofits across different cities. Thus, even identical retrofit measures can produce different outcomes depending on local microclimates, industrial characteristics, spatial structures, municipal ordinances, and financial support programs. These differences highlight the need to standardize baseline datasets and apply locally calibrated coefficients before conducting reliable economic modeling. The city-specific variations identified in this analysis are subsequently incorporated into a multilayered analytical framework that integrates the core analytical dimensions, dataset utilization practices, and relevant legislative provisions.

4. IDENTIFICATION OF KEY ISSUES THROUGH COMPARATIVE ANALYSIS

A synthesis of the international trends discussed in Chapter 2 and the domestic conditions analyzed in Chapter 3 identified six structural issues associated with renewable energy retrofits in aging, small-scale residential buildings in South Korea (Table 13). Because these issues are closely interconnected, the proposed improvements were developed from an integrated perspective, addressing overlapping challenges rather than treating each issue independently.

Table 13. Comparative Analysis of Key Issues in South Korea and Europe

Problem	Korea	Europe
1. Systematic absence of data	Detached and small-scale housing excluded from building energy DB; no post-retrofit monitoring	Institutionalized BSO, continuous monitoring, and KPI-based evaluation
2. Policy bias toward public buildings and lack of private support	Public-sector bias; private interest subsidy suspended(640 detached houses)	Diverse support schemes, including one-stop shops for private and low-income households
3. Lack of diverse renewable energy data	Insufficient demonstration and operation data on PV-geothermal hybrids, etc.	Systematic data building through GEO4CIVHIC, etc.
4. Lack of passive-active design integration	Mainly fragmented passive improvements(windows, insulation)	Active adoption of combined passive-active renewable strategies
5. Structural limits in economic feasibility	Negative NPV under current policy; reliance on high-interest loans	Interest-free/low-interest loans, tax incentives, energy communities
6. Insufficient performance verification and follow-up management	No institutionalized post-completion verification; performance gap unidentified	Analysis of certified vs. measured performance gaps and follow-up management systems

First, systematic gaps exist in the collection of fundamental building energy data. Detached houses and small-scale multifamily housing are excluded from the national building energy database, and operational data following retrofits are not systematically collected, even under existing green remodeling initiatives. In contrast, European frameworks incorporate requirements for building energy monitoring, continuous real-time data collection, and key performance indicator(KPI) based performance evaluation.

Second, existing policies focus disproportionately on public buildings. Consequently, substantive support for privately owned detached houses and multifamily residential buildings remains limited, despite private buildings accounting for 96% of the total building stock.

Third, domestic empirical evidence and long-term operational data on renewable energy technologies other than photovoltaics(PV) are insufficient. In particular, the application of geothermal and solar thermal technologies in small-scale residential buildings lacks adequate validation. By contrast, European initiatives, such as GEO4CIVHIC, systematically collect data on geothermal retrofits in residential buildings.

Fourth, domestic green remodeling remains focused on isolated passive improvements, such as window replacement and insulation upgrades. European policies, in contrast, promote integrated systems that combine heat pumps, photovoltaics, and geothermal energy as core components of building retrofits.

Fifth, limited economic feasibility under current government policies discourages voluntary participation in the private market. Substantial negative net present values(NPVs) have been identified under existing support conditions. To address these economic barriers, European countries have developed financial mechanisms, including interest-free or low-interest loans, tax incentives, and energy community models.

Sixth, post-retrofit energy performance verification has not been institutionalized in South Korea, leaving insufficient empirical evidence to demonstrate the effectiveness of renovation measures. For example, Spain has established an ex ante assessment framework to examine performance gaps between predicted energy performance certificate ratings and actual measured energy consumption, alongside post-occupancy management procedures.

Based on these findings, this study proposes six policy recommendations and improvement measures to promote renewable energy retrofits and establish a foundational spatial database for aging, small-scale residential buildings.

First, mandatory energy performance monitoring and supporting data infrastructure should be established to develop a baseline spatial dataset. Detached houses and multifamily housing with fewer than 200 units should be incorporated into the national building energy database. In addition, mandatory energy performance monitoring should be implemented for at least three to five years after project completion for green remodeling projects. Drawing on European building energy management systems and detailed data analysis frameworks, a KPI framework should be developed to classify performance indicators by building use and energy source.

Second, diverse renewable energy demonstration programs should be introduced. Drawing on European initiatives such as GEO4CIVHIC, national demonstration projects should evaluate PV-geothermal hybrid systems and photovoltaic-thermal (PV-T) systems tailored to South Korea's climatic and geological conditions. These systems should be applied to detached and multifamily residential buildings. The resulting projects would provide a basis for systematically establishing design standards, construction specifications, and performance verification datasets.

Third, a comprehensive financial support framework should be developed for privately owned, small-scale residential buildings. The current policy of providing interest subsidies for loans, which remains heavily influenced by high market interest rates, should be supplemented or replaced by a tailored combination of interest-free or low-interest loans, direct cash subsidies, and tax incentives design based on models such as those of Germany(1% interest rate with debt relief or cash grants scaled by the energy efficiency class), Italy(superbonus 110% program with transferable tax credit), and France(tiered subsidies based on household income).

Fourth, an integrated one-stop-shop(OSS) platform should be established to support green remodeling in privately owned residential buildings. Drawing on the OSS model promoted by the EU, municipal-level service centers should provide comprehensive assistance throughout the remodeling process, including consultation, diagnostics, design, construction, financing, and post-occupancy monitoring. These services should also be coordinated with existing housing welfare programs, such as home repair assistance for low-income households and vacant property revitalization initiatives.

Fifth, comprehensive design guidelines integrating passive measures, active building systems, and renewable energy technologies should be developed. These guidelines should account for the structural and spatial constraints of small-scale residential buildings, including limited roof areas and structural load-bearing capacity. They should provide integrated design scenarios combining passive measures, such as insulation and improved fenestration; active systems, such as heat pumps and heat recovery ventilation; and renewable energy technologies, including PV and geothermal systems. Appropriate technical combinations should be determined according to building age, climatic conditions, and operational energy demand.

Sixth, mandatory green remodeling requirements for privately owned residential buildings should be introduced in phases and supported by a stronger legal framework. However, these requirements should be accompanied by robust financial support mechanisms, including interest-free or low-interest loans, direct grants, and tax incentives. Coordinating regulatory requirements with financial assistance would help maintain market feasibility and promote equitable participation in green remodeling.

5. CONCLUSION

This study aimed to assess the current state of building energy data collection in South Korea, identify structural deficiencies in the baseline spatial data required to evaluate the techno-economic feasibility and thermal performance of green retrofits, particularly renewable energy retrofits involving geothermal and photovoltaic systems in aging, small-scale residential buildings, and propose strategic directions for improvement. The analysis revealed several major barriers to renewable energy retrofits in aging, small-scale residential buildings in South Korea. These include policy frameworks that prioritize public buildings at the expense of the private residential sector, a systemic lack of baseline data, and a fragmented approach to renewable energy integration that relies heavily on photovoltaic systems alone. In contrast, the European Unio's Renovation Wave initiative, its regulatory framework, data infrastructure supported by building energy management systems (BEMS), and multilevel financing mechanisms offer important strategic directions for domestic policy development. Establishing national demonstration programs that incorporate diverse renewable energy technologies, including geothermal, solar PV, and solar thermal systems, in small-scale residential buildings is essential. These initiatives must be accompanied by

the systematic collection and integration of baseline spatial data. Building on these foundations, integrated design guidelines, multilayered financial incentives, and phased regulatory mandates can be developed and implemented more effectively to support national carbon neutrality targets. To operationalize these improvement strategies at the individual-building level, a multilayered hybrid data architecture must be established to integrate spatial information, energy performance data, economic and cost data, and operational and maintenance records. This study contributes academically and practically by proposing an integrated, data-driven framework for systematically consolidating baseline datasets that are currently fragmented across multiple systems. Building on this architecture, future research will focus on developing a practical data platform that organizes datasets on geothermal and photovoltaic equipment and incorporates local municipal ordinances and financial support programs into an operational framework.

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