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*Cost-effective building stock decarbonization and seismic resilience: Incorporating
EPBD implementation in renovation plans and passports.*

WP4

Financing Sustainable Renovations: Case Studies

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Executive Summary

Deliverable 4.3 presents a structured market analysis of financing instruments for sustainable building renovations, focusing on highly energy-efficient, seismic-resilient and decarbonized outcomes. It compiles 5–8 detailed case studies, based on national and transnational examples, supported by a literature review and is standardized through a common template to ensure comparability. Each case study explores the organizational context, financing purpose, costs and resources as well as risk and return considerations. The results are consolidated into accessible factsheets, making different financing approaches transparent and evaluable. These case studies form the foundation for developing a generic decision-making framework (D4.4) and subsequent decision-making tool (D4.5), which will guide stakeholders in selecting effective financing solutions for sustainable renovations.

List of Abbreviations

BCR	Benefit-Cost Ratio
BIM	Building Information Modelling
CAPEX	Capital Expenditure
CFRP	Carbon Fiber Reinforced Polymer
CO2	Carbon Dioxide
EC8	Eurocode 8 Standard
EE	Energy Efficiency
EMS	Energy Management System
EnPC	Energy Performance Contracting
ENPV	Economic Net Present Value
EPBD	Energy Performance of Buildings Directive (EU)
EPC	Energy Performance Certificate
ERR	Economic Rate of Return
ESCO	Energy Service Company
ESG	Environmental, Social, And Governance
EU	European Union
EU RRF	Recover And Resilience Facility
FNPV	Financial Net Present Value
FRG	Fiber-Reinforced Cement Plasters
FRR	Financial Rate of Return
GHG	Greenhouse Gas Emissions
GWP	Global Warming Potential
HP	Heat Pump
HVAC	Heating, Ventilation and Air-Conditioning
IRR	Internal Rate of Return
LCA	Life Cycle Assessment
MECE	Ministry Of Environment, Climate and Energy
MEP	Mechanical, Electrical and Plumbing
MEPS	Minimum Energy Performance Standards
NPV	Net Present Value

NRRP	National Recovery and Resilience Plan
nZEB	Nearly Zero-Energy Building
OPEX	Operational Expenditure
OSS	One-Stop Shop
PPP	Public Private Partnership
PV	Photovoltaic
RC	Reinforced Concrete
RES	Renewable Energy Sources
SFH	Single-Family House
SHW	Sanitary Hot Water
SVRK	Government Office for Development and EU Cohesion Policy
VAT	Value Added Tax
ZEB	Zero-Emission Building
ZEB	Zero-Emission Building
ZGNL	Zavod Za Gluhe In Naglušne Ljubljana
ZVKDS	Institute For the Protection of Cultural Heritage

List of Indexes

$Q_{H,nd,an}$	Annual useful heat demand for space heating
$E_{tot,del,an}$	Annual total delivered energy
$E_{ptot,an}$	Annual total primary energy
$E_{pren,an}$	Annual total primary energy demand covered by renewable source
$M_{CO_2,an}$	Annual operational greenhouse gas emissions

Glossary

CAPEX	Capital expenditures (CAPEX) are costs that occur when purchasing, improving or maintaining physical assets of an renovation. Eligible capital expenditure refers to investments in tangible or intangible assets that are necessary for the project's implementation and comply with the grant's funding rules. Non-eligible capital expenditure includes costs that do not meet the grant's criteria.
Energy performance Certificate (EPC)	An official document that rates a building's energy efficiency and overall performance based on standardized calculations. It provides key information such as the building's energy class, estimated energy consumption, and recommendations for improvement. EPCs are required under the EU Energy Performance of Buildings Directive (EPBD) and are used to benchmark, compare, and monitor renovation progress toward national and EU energy targets.
Net Present Value (NPV)	Net present value (NPV), is used to calculate the current total value of a future stream of payments. If the NPV of a project or investment is positive, it means that the discounted present value of all future cash flows related to that project or investment will be positive, and therefore attractive. A negative NPV means the investment is not profitable.
Internal Rate of Return (IRR)	The Internal Rate of Return (IRR) is the annual rate of growth that an investment is expected to generate and is used to estimate the profitability of potential investments. IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. Generally speaking, the higher an internal rate of return, the more desirable an investment is to undertake. It can be used when comparing potential investment options.
Energy Performance Contracting (EnPC)	A contractual arrangement between a building owner (or client) and an Energy Service Company (ESCO), in which the ESCO implements energy efficiency measures and is paid back through the cost savings achieved over time. The ESCO typically guarantees a certain level of energy savings, assumes performance risk, and may arrange financing for the upfront investment. EnPCs enable building owners to improve energy performance without initial capital expenditure, making them a key mechanism for financing sustainable renovations.

1 | Introduction

The GreenRenoV8 project supports the implementation of national and EU-level building renovation strategies with the ultimate goal of achieving a resilient, inclusive, and carbon-neutral building stock across Europe. Its core ambition lies in integrating energy renovation with seismic risk mitigation, especially in vulnerable and earthquake-prone regions. Key pillars of the project include financial mechanisms and related replicable sustainable renovations implementation models that can guide both public and private actors.

Deliverable 4.3 specifically contributes to this mission by collecting, structuring, and analysing case studies that illustrate how various financing schemes support sustainable, seismic, and energy renovations. These case studies serve as empirical input for model-building, risk assessments, and policy innovation within the project's technical and financial toolkit. Specifically, they will serve as input to the GreenRenoV8 toolbox (D4.5), enabling the development of sustainable renovations financing models, renovation passports, and integrated financial instruments.

The goal of this deliverable is to explore how integrated building renovations – those that combine sustainable, seismic, and energy-related improvements – have been financed and what results they have achieved. Using a comprehensive set of key performance indicators (KPIs) encompassing economic, financial, EE, seismic, and environmental dimensions, the deliverable analyses real-world examples of projects that have gone beyond standard EE upgrades.

These examples will showcase renovations that holistically address multiple aspects of building performance – from energy and seismic safety to embodied emissions, climate adaptation, fire safety, and compliance with evolving standards such as ZEB and MEPS. By documenting how such projects have been structured, financed, and implemented, the deliverable aims to demonstrate that sustainable renovations can generate long-term environmental, social, and economic value.

This is important because the transition to a resilient, low-carbon building stock requires massive investments, far beyond what can be covered by grants or public funding alone. To scale up renovation efforts, financial institutions must be engaged as active partners. However, many still lack the knowledge, data, and confidence to evaluate or value the multiple co-benefits of sustainable, integrated renovations – such as improved structural safety, comfort, and health, or reduced carbon footprints.

By providing evidence of successful examples and measurable outcomes, this deliverable seeks to bridge the information gap between project promoters and financial actors, showcase examples of financing models that enable comprehensive renovations beyond EE alone, and highlight the broader impact of such investments measured through KPIs. Ultimately, the analysis underlines that integrated renovations are not a cost, but a strategic investment in sustainability and resilience.

Methodology and data collection

To ensure consistency and support the case study selection process, a *Guide for Selecting GreenRenoV8 Case Studies* (Annex I) and an accompanying Excel-based Case Study Data Acquisition Template (Annex II) were developed. The Excel template was structured into six main sections:

- ▶ **Case Study Overview** summarized the context of the project, including its objectives, key stakeholders, and the financing approach applied.
- ▶ **Renovated Buildings** describes the building characteristics, such as type, use, age, baseline condition, and the renovation measures implemented.
- ▶ **Sustainability Performance** highlights the environmental, social, and economic impacts of the renovation.

- **Funding** outlines the financing sources, instruments, structuring and any support mechanisms used to mobilize capital.
- **Financial and Economic Key Performance Indicators** presents key indicators such as investment costs, net present value (NPR), internal rate of return (IRR) and payback period (PP).
- **Energy Efficiency, Environmental and Seismic Key Performance Indicators** captures technical results, including energy savings, CO₂ reductions, and improvements in structural resilience.

Case study selection was based on the expert judgement guided by a shared logic model presented in the Guide. However, some flexibility was allowed as it wasn't necessary for the case studies to include a full elaboration of all elements. A case study was to reflect the actual status and availability of data and implementation maturity. They reflect best practices as well as learning experiences, successes and challenges, from real-life implementation contexts.

The data collection process combined **desk research** with **direct inputs from project partners** operating in the pilot countries. Partners leveraged their established professional networks and local connections to identify and document relevant renovation cases, allowing access to first-hand and context-specific information. However, the availability and quality of data varied significantly across countries. In some cases, obtaining detailed information proved challenging when project documentation was not publicly accessible or when data confidentiality limited disclosure. As a result, not all financial indicators—particularly those from investment documentation prepared prior to project implementation—could be fully retrieved. Despite these limitations, the collected material provides a robust and representative basis for analysing real-world financing mechanisms and practices across diverse national contexts.

A **Case Study Comparative Table** of case studies provides an overview of the types of buildings included in the analysis, the renovation aspects addressed, the funding intensity (expressed as funding per square meter of total floor area), the financing structure, and the key performance indicators (KPIs) used to assess the benefits of the implemented renovation measures.

Based on the table, the case studies are presented in a systematic manner using an index composed as follows: **CS (Case Study) – country code (e.g., SI) – building type**.

Table 1: Summary table of all case studies.

Case number	1	2	3	4	5	6	7	8	9
County	IT	GR	GR	BE	AUT	AUT	SI	SI	SI
Building type	Public building - primary school	Residential building - Single-family house	Non-residential building – hospital	Residential building – Single-family house	Residential building – apartment block	Residential building – Single-family house	Public building – primary school	Public building – Educational and healthcare buildings	Residential building – semi-detached residential building
Type of measures implemented									
EE	✓	✓	✓	✓	✓	✓	✓	✓	✓
RES	✓	✓			✓	✓	✓		✓
Seismic	✓		✓	✓			✓	✓	
Other	✓				✓	✓	✓		✓

2 | CS1 – IT – Public building – educational building

2.1 Case Study Building Overview

Building Description

The case study building is a public-school facility in Maresca, a mountain municipality in Tuscany. It accommodates both kindergarten and primary school functions and is municipally owned and managed. Constructed in 1968, the building is a two-storey structure with masonry (stone rubble) walls and brick–concrete floor slabs, typical of the pre-code school building stock of the 1960s. It has a total floor area of 1,100 m², all of which underwent renovation. The building is situated in seismic zone 2, with a pre-intervention seismic index (z_e) of approx. 0.19, underlining its structural vulnerability prior to renovation.

Key Building Data	
Building classification	Public building – Educational building
Renovation scale	Building, programme
Target group	Building owners, property managers, public administrations, school community (headteacher, staff, families) for continuity of teaching, Distribution System Operator e-Distribuzione for grid connection.
Number of buildings	1
Building age	Built in 1968; 57 years
Location	Maresca, Tuscany, Italy
Short building description	Two-story building with masonry (stone rubble) walls and brick–concrete floor slabs. The facility is used as a primary school and kindergarten.
Renovation Indicators	
Total floor area	1,100 m ²
Renovated floor area	1,100 m ²
Masonry walls strengthened	1,900 m ²
PV system	550 m ²
Renovation Measures	
Energy	- Existing energy features (from prior renovations) include double glazing, roof insulation and external wall insulation already present; diesel (gas-oil) heating in operation. - No envelope/HVAC replacement in this renovation–PV system is the first step of a staged energy upgrade, designed to remain compatible with future insulation/HVAC improvements.

Renovation Measures

Seismic Resilience	- Strengthening of masonry with CAM® stainless-steel active ties on approx. 1,900 m². - Creation of a rigid roof diaphragm.
Renewable Energy	17.64 kWp rooftop PV system (42×420 W, 2 strings) with transformerless 17 kW inverter, CEI 0-21 interface protection (SPI/DDI). - DC/AC boards in the attic. - Production meter and grid connection via e-Distribuzione.
Other Measures	- Roof works and improved access included local waterproofing renewal in the PV system area (removal, reinforced screed, new membrane) and enlarged roof hatch, permanent fall-protection and temporary scaffolding for safe installation. - Operational safeguards included maintained egress routes and safety standards, and control of dust/noise and indoor air quality during works.

Pictures



Goals of the Renovation

The main goal of the renovation was to improve seismic safety of the building while ensuring the continuity of teaching through low-intrusion strengthening techniques and by implementing the measures during the summer break. The project sought to reduce energy demand and CO₂ emissions through the installation of PV system and in order to prepare the building for future EE upgrades in line with the nZEB trajectories.

The intervention also pursued transparency and cost-effectiveness through public procurement on the START platform, with the ambition of serving as a replicable model for other schools in mountain areas. Monitoring and evaluation through EPCs, PV system performance data and structural acceptance tests were foreseen to generate reliable evidence and KPIs for policy and technical replication.

Trigger for Renovation

The renovation was triggered by urgent seismic safety needs, the school's location in seismic zone 2 and a very low pre-intervention index, combined with the availability of public funding through the START platform.

Specific Requirements, Challenges and Barriers

The renovation had to meet strict requirements to balance safety, continuity of teaching, and long-term sustainability in an occupied school located in a rural mountain area. As such, all works were carefully phased during the summer months to ensure uninterrupted teaching activities. Low-intrusion seismic strengthening was

applied, compatible with occupancy and executed through phased interventions, including the installation of a rigid roof diaphragm without adding significant mass or stiffness. Safety was prioritized by maintaining egress routes, controlling dust and noise, and protecting indoor air quality. The seismic intervention aimed to improve structural safety for pupils and staff and to support broader community goals, ensuring the building's resilience and long-term serviceability.

The project also contributed to municipal sustainability objectives through the installation of a rooftop PV system, aligning with plans for the school's participation in a local Energy Community. The PV system installation complied with CEI 0-21 standards, covering interface protection, surge control, TT earthing, and coordination with e-Distribuzione for grid connection. Roof works were confined to the PV system area and included waterproofing renewal, reinforced screed, and permanent fall-protection to ensure long-term durability. All interventions were planned to remain compatible with future envelope and HVAC upgrades, while mountain-site logistics were carefully managed to maintain a minimal environmental footprint.

The main barrier was the mountain location, where harsh winters limited the construction window and complicated material transport. The chosen CAM® seismic strengthening system required extensive access to masonry surfaces within the occupied building, making precise scheduling critical. Additional challenges included roof access and safety, addressed through the installation of an enlarged hatch, scaffolding, and improved fall-protection systems. Transparent procurement procedures and post-works documentation – such as structural acceptance tests, EPCs, and PV system monitoring – ensured traceability and compliance throughout the project.

Implementation and stakeholders

Communication activities were carried out through multiple channels to ensure transparency and stakeholder engagement. Project information and procurement documents were published on the regional START platform with CUP/CIG codes and in the Municipality's "*Amministrazione Trasparente*" section. The local press (Il Tirreno, Linea Libera) reported on the seismic upgrading and PV system installation, including funding details. The school management and parents' committee were regularly informed during planning and execution to safeguard teaching continuity, while on-site signage was displayed in line with public procurement regulations.

Renovation Measures

The renovation primarily addressed seismic safety, complemented by the installation of a PV system as the sole energy-related measure in this phase. Structural resilience was improved through the strengthening of approx. 1,900 m² of masonry with CAM® stainless-steel active ties and the creation of a rigid roof diaphragm, carried out with low-intrusion, phased summer works to keep the school operational. On the energy side, a 17.64 kWp rooftop PV system (42×420 W modules, transformerless 17 kW inverter) was added, with CEI 0-21 compliant protections and grid connection via e-Distribuzione.

The seismic strengthening of the building was carried out using the CAM (*Cuciture Attive per Muratura*) system, a highly reversible, minimally invasive, and rapidly applicable technique. The method involves creating small transverse holes—or shallow grooves where aesthetic considerations apply—through which thin stainless-steel ribbons or straps (approx. 6–8 mm thick) are threaded and subsequently concealed within the plaster layer. Since the system does not modify the structure's mass or stiffness distribution, it is particularly suitable for architecturally or historically sensitive masonry. In this case, the intervention covered roughly 1,900 m² of wall surface, yet it remains classified as a local, low-intrusion strengthening measure rather than a full structural retrofit.

Roof works included local waterproofing renewal, reinforced screed, and new membrane in the PV system area, as well as improved access through an enlarged hatch, permanent fall-protection, and temporary scaffolding. Throughout the process, safety and operational safeguards—such as maintaining egress routes, controlling dust/noise, and protecting indoor air quality—were strictly observed.

No new envelope or HVAC measures were implemented in this phase; instead, the PV system installation was conceived as a first step in a staged energy renovation pathway, designed to remain compatible with future upgrades.

2.2 Financing

The eligible costs for the building amounted to €778,650, of which €148,650 came from own funds and €630,000 from a capital grant. The seismic strengthening was supported by a €630,000 public grant awarded in 2018 under the Ministry of Education's Budget Law 2017, while the PV system and related roof waterproofing works were financed through a municipal budget allocation and tender planned for 2025. Future operating revenues will derive from bill savings through self-consumption and RID incentives (GSE) for exported electricity, with participation in a local Energy Community also planned.

The renovation was procured through the regional START platform under national public-works rules, ensuring compliance with Italian NTC standards for structures and CEI 0-21 requirements for grid-connected PV systems. Financing followed a public capital expenditure model (Design–Bid–Build), with no third-party involvement. Since the building received a public grant award in 2018 and was supported by a municipal budget allocation/tender for PV system in 2025 (under negotiation), the financing process did not involve the usual steps of securing debt or guarantees.

The financing involved the following partners:

- ▶ Investor: Municipality of San Marcello Piteglio (public owner/client)
- ▶ Managing authority: Ministry of Education (Budget Law 2017 grant)
- ▶ Intermediate body: Region of Tuscany (programme coordination/procurement platform owner – START)
- ▶ Responsible authority: Municipality of San Marcello Piteglio (Contracting Authority/RUP)

2.3 Sustainability Performance and KPIs

The sustainability performance of the case study building has been assessed through the following models and methods:

- ▶ Proxies for operational and embedded emissions: avoided CO₂ from PV system generation, estimated using national grid emission factors (proxy method).
- ▶ Energy Performance Certificates (EPCs): post-renovation as they are required for all public buildings. A pre-intervention EPC is not available.
- ▶ Other: Preliminary technical survey and roof preparation works; compliance with CEI 0-21 (national standard for grid connection of PV systems).

The following section provides an overview of the KPIs used to measure the renovation progress of the case study building. The indicators may rely on different approaches to value calculation, which are detailed in the last column.

Financial KPIs		
FNPV(C)	-€83,300	PV-only FNPV(C); seismic not applicable. 25y @4%; incremental CAPEX €112,538; $\alpha=0.50$; $P_{acq}=0.22$; $RID=0.08$; OPEX 1%; 0.5% degradation.
Simple Payback Period	56 years	Using incremental CAPEX €112,538 in worst-case; 56 years in base scenario (incremental).
Financial Discount Rate	4 %	Standard EU reference rate applied for financial appraisal.
Economic KPIs		
ENPV	€120,000	Economic NPV includes avoided seismic losses (ΔPAM).
ERR	5.5 %	Economic IRR with $\Delta PAM=€43,290/y$ (50y) + PV net (25y, $\alpha=0.50$), total CAPEX.
Social Discount Rate	3 %	Standard EU reference for socio-economic appraisal (EC CBA Guide 2021).
Benefit-Cost Ratio	1.5	$BCR > 1$ indicates socio-economic viability. $\Delta PAM=43.3k€/y$ @3% + PV; ENPV positive.
Energy KPIs		
Energy savings per building	18.9 kWh/m ² a	Value expressed per internal floor area only; it represents grid electricity offset by PV.
Amount of primary energy saved	21,000 kWh/a	Annual PV system generation offsets approx. 0.021 GWh of primary energy use.
Share of energy from RES	35 %	PV system covers approx. 35% of estimated school electricity demand, reducing reliance on fossil fuels.
Energy from RES	17.64 kWp installed; approx. 20,997 kWh/a generated.	Rooftop PV system installed: 17.64 kWp capacity with expected output of approx. 21 MWh/a.
Environmental KPIs		
Reduction in carbon emissions	6.9 tCO ₂ /a	PV system generation 20,997 kWh/a displacing grid electricity at 0.33 kgCO ₂ /kWh.
Annual operational GHG reduction	6.2 kgCO ₂ eq/m ² /a	CO ₂ reduction per internal floor area: 6,930 kgCO ₂ /y ÷ 1,110 m ² .
Avoided CO ₂	5.2–8.4 tCO ₂ /a	Assumption 0.25–0.40 kgCO ₂ /kWh × 20,997 kWh.
Seismic Resilience KPIs		
Seismic safety index	0.8	Index raised from 0.19 pre-renovation to 0.8 post-renovation.
Walls strengthening	1,900 m ²	Masonry strengthened (CAM®) and rigid roof diaphragm.

2.4 Lessons Learned and Key Recommendations

Integrating seismic safety and energy efficiency (EE) in one school project proved feasible and mutually reinforcing. Structural safety (CAM® + rigid roof diaphragm) was ensured while enabling long-term energy savings through PV. Seismic, energy, and social aspects were all addressed, making the intervention holistic. In a mountain, occupied-school context, success depended on careful phasing around the school calendar and low-intrusion works; early roof pre-works (waterproofing, screed) and safe access/fall protection were decisive. Governance mattered as much as technology: transparent START tendering, CUP/CIG traceability, and clear communication with the school community-built legitimacy and acceptance. This comprehensive approach shows that even mid-sized rural schools can be replicable models of resilience, decarbonisation, and community benefit—if backed by stable funding and simple, comparable reporting.

Key recommendations:

- ▶ Plan simple, low-intrusion works: Schedule around school activities; prioritise buildable details and critical summer operations.
- ▶ Pre-survey roof and envelope: Assess conditions and budget early pre-works (waterproofing, access, fall protection) to avoid delays.
- ▶ Sequence “seismic first, energy next”: Detail CAM® works compatible with future insulation/facade upgrades (no-drill zones, anchor spacers, thermal-bridge control).
- ▶ Ensure transparent governance: Use e-procurement, full traceability, milestone payments, and stakeholder updates to build trust and replicability.
- ▶ Keep data light but useful: Require post-intervention EPC, PV metering, and a concise before/after KPI summary. Assign data management roles.
- ▶ Integrate safety and interfaces: Define CEI 0-21 responsibilities early; include permanent roof access and fall protection.
- ▶ Finance with buffers: Include contingency and align a “Phase 2 – Energy” package with MEPS/nZEB goals and grants.
- ▶ Bundle envelope + generation: Combine insulation, efficient windows, and HVAC/ventilation with PV to meet MEPS and reduce heating demand.
- ▶ Energy class context: The APE pre/post is not yet available; for similar 1960s masonry schools, pre-renovation performance is typically low (approx. class E–G)—to be confirmed by audit. Without envelope/HVAC upgrades, PV system improves operating costs/emissions but does not materially change winter thermal performance.
- ▶ Enhance indoor comfort: Next phase should target air quality, lighting, acoustics, and overheating control.
- ▶ Optional monitoring: If the seismic risk justifies it, consider light-touch structural monitoring (inspection plan, crack gauges on critical walls) to complement the final structural testing and certification (collaudo).
- ▶ Community value: Define CER governance/metering rules so PV system benefits are tangible to the school/community (e.g., share of savings for school activities).
- ▶ Replicability kit: Archive the phasing plan, standard details (CAM® + future insulation interfaces), tender specs and KPI template so other schools can reuse the model.

3 | CS2 – GR – Residential building – Single-family house

3.1 Case Study Building Overview

Building Description

A single-person residential apartment located in the centre of Athens served as a demonstration site for the Drive0 H2020 project. The building has a total floor area of 108 m² and has been the demonstrator building of the EU's Horizon 2020 Drive0 project. The building was renovated through a combination of measures aimed at achieving nZEB standards.

Key Building Data	
Building classification	Residential building – Single-family house
Renovation scale	Building-level
Target group	Building owners
Number of buildings	1
Building age	Built in 1970; 55 years
Location	Athens, Greece
Short building description	A residential single-person apartment building located in the city centre of Athens in the 1970s
Renovation Indicators	
Total floor area	108 m ²
Renovated floor area	108 m ²
Masonry walls strengthened	
PV system	25–30 m ²
Renovation Measures	
Energy	Wall and roof insulation
Seismic Resilience	
Renewable Energy	- PV system installation - Battery 7.7 kWh - Heat pump - Thermal hot water
Other Measures	

Pictures



Goals of the Renovation

The renovation aimed to achieve the nZEB standard, while improving indoor environmental quality and enhancing the building's resilience to climate change. The process addressed several key challenges, including the reduction of whole life-cycle greenhouse gas (GHG) emissions, integration of RES, and improvement of data availability, accessibility, and quality. It also involved a comprehensive cost-benefit assessment to capture multiple benefits beyond energy savings. Specific challenges tackled during the project included determining the appropriate renovation approach, identifying effective financial instruments, addressing energy poverty and the needs of vulnerable households, and implementing a robust monitoring and performance evaluation framework.

Trigger for Renovation

The renovation was triggered by multiple co-founded schemes, governmental initiative "Exoikonomo 1" and inclusion in the EU's Horizon 2020 project Drive0.

Specific Requirements, Challenges and Barriers

The renovation process required coordination between multiple stakeholders. Continuous communication between the homeowner and the renovation team (SALFO) was maintained through phone calls, on-site visits, meetings, and discussions. Specific challenges mentioned in the project included determining the appropriate renovation approach, identifying effective financial instruments, addressing energy poverty and the needs of vulnerable households, and implementing a strong monitoring and performance evaluation framework.

Implementation and stakeholders

Communication between the homeowners and the renovation team (which from the side of Drive0 project was SALFO company) was maintained through phone calls and frequent on-site visits, meetings, and discussions.

Renovation Measures

The building underwent a comprehensive renovation that included wall and roof insulation, as well as the installation of a PV system on the roof with a total surface area of approx. 25–30 m². The PV system installation was complemented by a battery storage unit for storing the generated electricity and an optimization and monitoring system to track PV system production at the module level. A HP was installed to provide space heating and domestic hot water, supported by a solar thermal system dedicated to hot water production. The dwelling has been continuously monitored to assess both its overall energy performance and indoor air quality.

3.2 Financing

The total eligible costs for the case study building amounted to approx. €50,000–53,000. Of this, €8,000–10,000 was allocated to the energy retrofit, which included wall and roof insulation, while €42,000–43,000 was dedicated to the installation of a RES and efficiency system comprising PV system on the roof, a battery storage unit, an optimization and monitoring system for PV system production at the module level, a HP, thermostatic radiator heads, and a solar thermal system. The energy retrofit component was co-financed with the above-mentioned €8,000–10,000 through a national insulation support program “Exoikonomo 1”, including also a small amount of own funds from the homeowner.

3.3 Sustainability Performance and KPIs

The sustainability performance of the building renovation was assessed through in-situ monitored data collected as part of the Drive0 project. Monitoring focused on thermal comfort, indoor air quality, and energy performance, using measurements of indoor air temperature and primary energy demand before and after renovation. Data were analysed seasonally (summer and winter) to evaluate energy efficiency improvements and comfort conditions. KPIs were derived from these monitored datasets.

The following section provides an overview of the KPIs used to measure the renovation progress of the case study building. The indicators may rely on different approaches to value calculation, which are detailed in the last column.

Energy KPIs		
Energy savings per building	78–80%	Based on $E_{\text{tot,del,an}}$
Amount of primary energy saved	14.47 MWh/a (93%)	$E_{\text{Ptot,an}}$ (before renovation) = 144 kWh/(m ² a) $E_{\text{Ptot,an}}$ (after renovation) = 10 kWh/(m ² a)
Share of energy from RES	70%	$E_{\text{Pren,an}}/E_{\text{Ptot,an}}$
Energy from RES	5 kW installed	7 MWh produced
Environmental KPIs		
Reduction in carbon emissions	89 %	Based on $E_{\text{tot,del,an}}$

3.4 Lessons Learned and Key Recommendations

The renovation of the case demonstrated that targeted interventions on thermal and electrical systems can significantly reduce energy demand and improve indoor thermal comfort, even in older building stock. Survey results indicated a high level of satisfaction among all participant groups, homeowners, local partners, and engineers, with average ratings of 2.65/3 overall. The project effectively demonstrated the benefits of deep and circular renovation approaches promoted by Drive0, emphasizing the importance of system monitoring, stakeholder communication, and data-driven evaluation.

Key recommendations include:

- ▶ Continue combining national retrofit schemes with EU-funded initiatives to enhance financial feasibility.
- ▶ Strengthen monitoring of indoor air quality alongside energy performance.
- ▶ Maintain close collaboration between users, technicians, and project coordinators to ensure smooth implementation and knowledge exchange.
- ▶ Further explore optimal set-point management in HP operation to prevent excessive cooling or heating periods.

4 | CS3 – GR – Non-residential building – Hospital

4.1 Case Study Building Overview

Building Description

The case study building is the General Private Clinic “I. Gavrilakis”, a non-residential healthcare facility located in Chania, Greece, and owned by IASIS S.A. The clinic operates as a private medical center and was originally constructed between 1966 and 1977, with subsequent additions and renovations in 1976, 1993, and 2002. The total building area covers approx. 568 m².

Key Building Data	
Building classification	Non-residential building – hospital
Renovation scale	Building
Target group	Building owners, property managers, healthcare operators
Number of buildings	1
Building age	Built between 1966–1997 with later additions in 1976, 1993 and 2002
Location	Chania, Greece
Short building description	Healthcare facility, a private clinic, originally building between 1966-1977, with subsequent additions and renovations.
Renovation Indicators	
Total floor area	568 m ²
Renovated floor area	568 m ²
Masonry walls strengthened	• 1055 m² - confinement of reinforced concrete columns and enhancement of their shear capacity • 350 m² - shear strengthening of beams • 75 m² - strengthening of slabs • 40 m² - joint strengthening
PV system	
Renovation Measures	
Energy	• Replacement of masonry infills with insulated walls.
Seismic Resilience	• Structural strengthening with CFRP composites (columns, beams, slabs).
Renewable Energy	/
Other Measures	/

Pictures



Goals of the Renovation

The primary goal of the renovation was to enhance the seismic resilience and extend the service life of the General Private Clinic building, while simultaneously improving its thermal performance through the installation of new insulated masonry infills.

The intervention addressed multiple aspects of building performance, including compliance with minimum energy performance standards (MEPS), seismic classification improvement, and mitigation of risks associated with intense seismic activity. In addition, the works contributed to better indoor environmental quality, adaptation to climate change, and the overall climate resilience of the facility.

The renovation also included the safe removal of hazardous materials, such as asbestos, ensuring a healthier and safer indoor environment. Extensive investigative and documentation activities were carried out prior to and during the works, comprising magnetic reinforcement scans (Ferroskan), the development of detailed vulnerability curves for structural elements, preparation of reinforcement drawings, and systematic photographic documentation to ensure transparency and traceability of the process.

Trigger for Renovation

The renovation was initiated following the identification of structural vulnerabilities through a detailed seismic assessment conducted in accordance with EN 1998-3 and KAN.EPE standards. The results highlighted the need for seismic strengthening to ensure structural safety and compliance with current regulations. In parallel, the project sought to modernize the building envelope to improve energy performance and occupant comfort, making the intervention both a structural and sustainable renovation initiative.

Specific Requirements, Challenges and Barriers

The renovation of the private clinic was carried out under strict operational and regulatory requirements, ensuring the uninterrupted functioning of the healthcare facility throughout the works. The project demanded

full compliance with national and European seismic codes, the safe removal and replacement of masonry infills, and detailed documentation of the existing reinforcement prior to structural interventions.

Several barriers were encountered during implementation, including the complexity of reinforcing an active healthcare environment, discrepancies between original design drawings and the actual as-built structure, and the need for careful demolition of existing infills without compromising load-bearing elements. In addition, the project faced material-related constraints, as it relied on insulation products characteristic of the period rather than modern high-performance alternatives.

Reduction of whole-life-cycle greenhouse gas emissions	The seismic strengthening extended the service life of the building, while the simultaneous energy upgrade – through the replacement of all external masonry walls with new thermally insulated ones – resulted in a significant reduction of the building’s overall carbon footprint. The primary factor which contributes to this reduction is the considerable decrease in emissions associated with occupants’ behavior (with the reduction in the usage of energy-intensive equipment and system).
Data availability, accessibility and quality	Extensive structural data (Ferrosan scans, fragility curves, photos and detailed designs).
EU Taxonomy	The project aligns with the objectives of the EU Taxonomy for adaptation to climate change by enhancing seismic resilience and fulfilling DNSH (Do No Significant Harm) requirements.
Do no significant harm and climate proofing	Interventions followed safe material handling and waste protocols, increasing seismic robustness and climate resilience of the envelope.
Cost benefit assessment	CFRP is the applied system for seismic retrofitting, chosen as the most efficient solution – meeting performance targets ($\lambda \leq 1$) with lower cost and intrusion and the least possible downtime.
Environmental, social and governance criteria	Significant improvement in environmental performance, occupant safety and governance through compliances with EN 1998-3 and KAN.EPE. (Greek Code for Assessment and Retrofitting of existing buildings).
Multiple benefits	The final result delivered seismic safety, energy improvement, extended lifespan and minimal disruption so it contributed to technical and socio – economic co-benefits.
Financing	The project was entirely financed through the owner’s own funds (IASIS S.A.) demonstrating both the viability and the potential of self-financed interventions for seismic strengthening and energy upgrading.

The project tackled key regulatory and technical challenges linked to compliance with the MEPS. It addressed the legal framework and renovation trigger points that determine when and how deep energy upgrades must occur. The selected renovation type combined EE and structural safety measures, ensuring regulatory alignment while improving building performance. Continuous monitoring supported verification of outcomes. The intervention also involved replacing existing uninsulated masonry infills with new insulated walls, significantly enhancing the thermal envelope and overall energy performance.

Implementation and stakeholders

Communication and coordination were supported through comprehensive technical documentation, which included reinforcement scans (Ferrosan), photographic records, detailed reinforcement drawings, monitoring reports, and the formal submission of permits to local authorities.

Renovation Measures

The renovation involved comprehensive structural strengthening of the building using carbon-fiber-reinforced polymer (CFRP) composites, applied to beams, slabs, and columns. The intervention included column confinement, shear strengthening of beams, and reinforcement around slab openings, all carried out in accordance with national and European seismic regulations (EN 1998-3 and KAN.EPE) and under valid building permits issued in 1967, 1993, and 2002.

During the retrofit process, all external infill walls were removed and reconstructed. The new walls were built using lightweight masonry units, with an intermediate layer of thermal insulation placed between the two layers, consistent with the construction standards and energy requirements of that period (2008). This energy intervention significantly improved the thermal performance of the building envelope compared to the former situation with uninsulated masonry infills. External plastering and finishing were applied over the retrofitted structure – including the CFRP systems – ensuring airtightness and minimizing thermal bridges wherever possible.

Prior to the strengthening works, detailed preparatory activities were undertaken, including the removal of old plaster and non-structural elements, Ferrosan investigations to assess reinforcement conditions, and the repair of corroded steel bars. The project was supported by comprehensive technical documentation, including reinforcement scans, vulnerability curves, reinforcement drawings, photographic evidence, and monitoring records, all archived as part of the official project documentation.

The combined result of the structural and energy interventions was a substantial reduction in heat losses, improved indoor thermal comfort, and a notable decrease in operational energy demand for heating and cooling. However, no renewable energy systems (such as solar panels) were installed at the time of the interventions, and no mechanical systems were replaced.

Through this integrated approach, the renovation effectively enhanced both the seismic resilience and thermal performance of the private clinic, ensuring its long-term structural safety, regulatory compliance, and operational comfort.

4.2 Financing

The renovation project was fully self-financed by the building owner, a private clinic, without any external subsidies, grants, or loans. The investment, provided entirely through private capital, covered all design, construction, and documentation costs.

The only parties involved were the building owner and the contracted construction company responsible for implementation. This fully private investment model reflects the owner's commitment to enhancing the clinic's structural safety and energy performance through direct reinvestment.

4.3 Sustainability Performance and KPIs

The evaluation of the building's performance was conducted using a combination of digital modelling tools and technical assessment methods. A Building Information Modeling (BIM) approach was employed to document and coordinate the renovation works, supporting accurate representation of structural and energy interventions. Proxies for both operational and embedded emissions were applied to estimate the building's overall environmental impact.

The seismic vulnerability assessment was carried out in accordance with EN 1998-3 and KAN.EPE standards, supported by reinforcement scans (Ferrosan) and the development of fragility curves for key structural

elements. Performance evaluation metrics included seismic performance indicators ($\lambda = S/R_m$ ratios), vulnerability curves, and compliance with established performance levels such as “Life Safety” and “Immediate Occupancy.” In parallel, the assessment also verified the improvement of thermal performance achieved through the installation of insulated masonry infills.

The following section provides an overview of the KPIs used to measure the renovation progress of the case study building. The indicators may rely on different approaches to value calculation, which are detailed in the last column.

Economic KPIs		
ENPV		Positive (enhanced seismic resilience and extended service life of a healthcare facility).
Benefit-Cost Ratio		[Qualitatively] >1 (because the avoided seismic risk and improved safety outweigh the intervention costs).
Environmental KPIs		
Reduction in carbon emissions		Indirect, through extended lifetime of building and avoided demolition/reconstruction.
Annual operational GHG reduction		Positive impact, since strengthening avoided replacement of the structure (qualitative).
Seismic Resilience KPIs		
Seismic safety index	1.0	Index raised from 0.8 – 0.9 pre-renovation to 1.0 post-renovation.
λ ratio (demand/capacity)	<1.0 for all	>1.0 in several vertical elements (shear deficiencies) pre-renovation to <1.0 for all post-renovation.

4.4 Lessons Learned and Key Recommendations

The renovation demonstrated that original design drawings may not always accurately represent the actual structural reinforcement, highlighting the importance of conducting thorough on-site investigations and detailed structural assessments, such as scans and vulnerability analyses, before any intervention. The use of CFRP composites proved to be a cost-effective and minimally invasive method for seismic strengthening, enabling continued operation of critical facilities during works. Integrating seismic strengthening with energy efficiency upgrades, such as the insulation of masonry walls, was shown to enhance the building’s long-term resilience, operational safety, and overall value. In complex settings like healthcare facilities, careful planning and phasing of demolition and construction works are essential to minimize disruption. Finally, maintaining comprehensive documentation—including scans, photographs, and continuous monitoring—ensures transparency, facilitates performance verification, and supports future maintenance and management of the building.

5 | CS4 – BE – Residential building – Single-family house

5.1 Case Study Building Overview

Building Description

The case study building is a terraced single-family house (SFH) located in Leuven, Belgium. The building represents a typical mid-20th-century Flemish terraced house, representative of roughly 25-30% of the regional housing stock. Originally, the structure was a stable that was converted into two dwellings in 1954, and no further renovation had been performed since then. Before renovation, the house was heated using gas stoves in the living rooms and a gas boiler for sanitary hot water (SHW), corresponding to an EPC label F – one of the lowest ratings.

Key Building Data	
Building classification	Residential building – Single-family house
Renovation scale	Building
Target group	Building owners
Number of buildings	1
Building age	Original construction date not known, transformed from a stable into two dwellings in 1954; approx. 70 years
Location	Leuven, Belgium
Short building description	Terraced single-family house
Renovation Indicators	
Total floor area	150 m ²
Renovated floor area	150 m ²
Masonry walls strengthened	
PV system	
Renovation Measures	
Energy	- Thermal envelope improvement. - High-efficiency windows and doors. - New mechanical ventilation system type C.
Seismic Resilience	
Renewable Energy	Heating system replacement with a heat pump for space heating and SHW preparation.

Other Measures

- Use of biobased materials for construction and insulation (wood, cellulose, loam plaster).
- Material circularity via reuse of ceramic tiles, wooden beams and parquet flooring; use of recycled cellular glass granulates for floor insulation.
- Demolition of a deteriorated rear volume and addition of a new storey at the back of the house.

Pictures



Goals of the Renovation

The goal of the renovation was to reduce the environmental impact of a SFH by using biobased and reclaimed materials, while comparing the outcomes to more traditional renovation approaches. More specifically, the renovation aimed to minimize both operational and embodied GHG emissions of the building, demonstrate the potential of circular and biobased materials in reducing the carbon footprint of residential renovation, and assess how the use of reclaimed materials influences the building's life-cycle environmental performance compared to conventional and biobased-virgin material scenarios.

The renovation addressed several key sustainability and resilience aspects, including compliance with MEPS, improvement of indoor environmental quality, and adaptation to climate change to enhance the overall climate resilience of the building.

The main challenges tackled involved the reduction of whole life-cycle GHG, integration of RES (replacement of gas stoves and gas boiler with HP, use of biobased construction materials), and adherence to Do No Significant Harm (DNSH) and climate-proofing principles. Additionally, the project incorporated a CBA and alignment with ESG criteria, emphasizing the pursuit of multiple co-benefits such as improved comfort, EE, and sustainability.

Trigger for Renovation

The main trigger for the renovation was the poor energy and structural performance of the existing dwelling, which had not undergone any significant renovation since its conversion from a stable to two dwellings in 1954. The building had an EPC label F, indicating very high energy use (over 500 kWh/m²/a) – one of the lowest efficiency levels in Flanders.

In addition to its high operational energy demand, the building also exhibited structural damage, particularly in the rear volume and parts of the storey floor, which necessitated partial demolition and replacement during renovation.

These deficiencies, combined with the broader objective of reducing the life-cycle environmental impact of the building sector, motivated a deep renovation using biobased and reclaimed materials to improve both EE and material sustainability.

Specific Requirements, Challenges and Barriers

A key requirement was compliance with Flemish and European energy performance and seismic regulations, as well as adherence to EPBD rules that restrict the use of reclaimed insulation materials unless their thermal properties are verifiable. This created a barrier to fully reusing materials, since the default thermal resistance values imposed by regulation led to thicker insulation layers and design limitations. Consequently, only 13 % of the materials were reused in this specific renovation project.

Other practical barriers included structural uncertainties when reusing materials – such as wooden beams with unknown origin or load-bearing capacity – which required higher safety coefficients and denser structural spacing. Additionally, market availability limited access to reclaimed materials meeting modern standards (e.g., beam dimensions). Finally, since cleaning and repairing reused materials was not yet accounted for in standard LCA tools like TOTEM, assessing their true environmental benefit was challenging.

Renovation Measures

The renovation involved a deep energy and material upgrade that combined structural repair, EE improvements, and the use of sustainable materials. The project included partial demolition and reconstruction of the rear volume, which was structurally unsound, and the addition of a new storey, increasing the building's total volume from 231 m³ to 414 m³. The outdated gas heating system and boiler were replaced with a HP for space heating and SHW, supported by a mechanical ventilation system.

To improve the building envelope, the renovation used biobased and reclaimed materials, such as reused ceramic tiles, wood fibre boards, cellulose insulation, and reclaimed wooden beams and parquet. The external walls were rebuilt as insulated timber-frame structures, new aluminium windows with double glazing were installed, and the flat roof was upgraded using EPDM membranes and cellulose insulation. The ground floor was rebuilt with recycled cellular glass granulates for insulation and reused sand layers, further reducing embodied energy.

5.2 Financing

The total eligible costs for the case study building amounted to €190,000, of which €60,000 was covered by the owner's own funds and €130,000 was financed through a regular loan. The loan carries an interest rate of 3.5% and a maturity period of 25 years.

5.3 Sustainability Performance and KPIs

The sustainability performance was measured using a LCA approach, applying the Belgian TOTEM tool. The assessment covered the entire life cycle of the building (before and after renovation) to evaluate both operational and embodied environmental impacts. Additionally, the building's performance was evaluated through the EPC, which improved from class F before the renovation to class A after completion. The whole life cycle GWP decreased by 75%, from 2,919 kg CO₂eq/m² to 724 kg CO₂eq/m², mainly due to reduced operational energy demand and replacement of fossil fuel systems with a HP.

The following section provides an overview of the KPIs used to measure the renovation progress of the case study building. The indicators may rely on different approaches to value calculation, which are detailed in the last column.

Environmental KPIs		
Reduction in carbon emissions	89 %	Operational GHG emissions decreased from 2,791 kg CO ₂ eq/m ² to 314 kg CO ₂ eq/m ² post renovation.
Annual operational GHG reduction	6.2 t CO ₂ eq/a	
Whole life-cycle GWP reduction	75 %	Reduction of whole life-cycle GWP from 2,919 kg CO ₂ eq/m ² to 724 kg CO ₂ eq/m ² .

5.4 Lessons Learned and Key Recommendations

The lessons learned emphasize the opportunities and constraints of using biobased and reclaimed materials in deep energy renovations. The project achieved a 75% reduction in total carbon footprint and an 89% decrease in operational emissions, proving that low-carbon retrofitting of older dwellings is feasible and highly effective. However, only about 13% of total materials were reused due to a combination of regulatory, technical, and market barriers. The Flemish EPBD regulations require conservative thermal performance assumptions for reused materials when test data is unavailable, leading to higher insulation thicknesses that often conflict with urban planning restrictions.

Similarly, uncertainty in the structural performance of reclaimed beams necessitated higher safety factors and denser spacing, increasing material use. The limited market availability of structurally compliant reclaimed materials (e.g., beams meeting the current 18 cm standard) further restricted reuse potential.

Key recommendations emerging from the renovation of this building are:

- ▶ **Adapt regulatory frameworks:** Update building and energy regulations to better accommodate reclaimed materials by allowing the use of certified performance data instead of applying default conservative assumptions that currently limit their use.
- ▶ **Integrate Module D in life-cycle assessments:** Incorporate Module D – which accounts for the “beyond the building life cycle” stage, including processes after demolition or deconstruction – into LCA calculations to fully capture the circular benefits of material reuse, recovery, and recycling that extend beyond the building’s operational life.
- ▶ **Strengthen policy and market support:** Develop policy instruments and market incentives that promote the use of biobased and reclaimed construction materials, including certification schemes, financial incentives, and supply chain support.
- ▶ **Ensure empirical performance validation:** Conduct post-renovation monitoring and calibration to validate modelled energy and emission data against actual performance, ensuring realistic and transferable results.
- ▶ **Broaden applicability and scalability:** Extend future analyses and renovation projects to include a wider range of building typologies, as current findings are representative of only 25-30% of the Flemish housing stock.

Overall, this case illustrates that combining deep energy retrofitting with circular material strategies can achieve substantial life-cycle carbon reductions, provided that regulatory, methodological, and market barriers are addressed to unlock their full potential.

6 | CS5 – AUT – Residential building – Apartment block

6.1 Case Study Building Overview

Building Description

The building, located on Prechtlgasse in Vienna's 9th district, is a classic Wilhelminian-era apartment house built around 1900. It is a solidly constructed, mid-block building, enclosed on both sides by adjoining structures, typical of the Gründerzeit period. The property comprises approx. 720–725 m² of usable residential area, distributed across four floors containing eight occupied apartments, with a brick-vaulted basement used for storage and ancillary functions.

Before the renovation, the building had uninsulated façades, an uninsulated top-floor ceiling, and windows that had been replaced roughly 15–20 years earlier, providing only moderate thermal performance. Heating and hot water were supplied by individual gas boilers in each apartment, and some units still relied on gas stoves for cooking. Due to these conditions, the building exhibited high thermal losses and an elevated heating demand of approx. 100 kWh/(m²a), making it a representative example of Vienna's aging, gas-dependent residential stock in need of comprehensive modernization.

Key Building Data	
Building classification	Residential building – Apartment block
Renovation scale	Building, Programme ("Raus aus gas" initiative)
Target group	Building owners, property managers
Number of buildings	1
Building age	Built in 1900; 125 years
Location	Vienna, Austria
Short building description	Residential apartment building with eight occupied units; historic Wilhelminian-era house
Renovation Indicators	
Total floor area	720 m ²
Renovated floor area	720 m ²
Masonry walls strengthened	/
PV system	18 kWp

Renovation Measures

Energy	• Insulation of attic and basement ceilings using wood-fibre materials. • Window and door upgrades (repairs, resealing, selective replacement). • Installation of mechanical ventilation with heat recovery. • Hydraulic balancing and smart control of heating distribution.
Seismic Resilience	
Renewable Energy	• Replacement of gas boilers with two central air-source HPs (approx. 30 kW total). • Installation of rooftop PV system (18 kWp) supplying renewable electricity to HPs and common areas. • Installation of buffer and hot water storage tanks for decentralized hot water supply. • Complete phase-out of fossil fuels and transition to all-electric systems.
Other Measures	• Integration of a digital energy monitoring and control system. • Preservation of the historic façade and architectural character. • Use of sustainable, low-carbon materials (e.g., wood-fibre insulation).

Pictures



Goals of the Renovation

The renovation of Prectlgasse 7 aimed to transform a historic, gas-dependent residential building into a climate-friendly, energy-efficient, and fossil-free property. The overarching goals were to eliminate natural gas use, reduce energy consumption and GHG emissions, and improve the thermal comfort and overall energy performance of the building. The project also sought to extend the building's lifespan, enhance indoor living quality, and contribute to Vienna's broader "Raus aus Gas" (Get Out of Gas) initiative promoting a sustainable, renewable-based urban building stock.

Aspects addressed

The renovation of Prechtlgasse 7 addressed several key environmental, technical, and social aspects, aligning with EU and national sustainability objectives:

- ▶ **Zero-Emission Building (ZEB):** The building achieved a complete fossil-fuel phase-out, operating entirely on renewable electricity and ambient heat (PV system + air-source HPs). Its operational CO₂ emissions were reduced to near zero, meeting ZEB objectives under the EU Taxonomy.
- ▶ **Minimum Energy Performance Standards (MEPS):** The renovation exceeded MEPS requirements, achieving an approx. 70% reduction in heating demand (from approx. 110 kWh/m²·a to approx. 32 kWh/m²·a), fully complying with Austrian and EU renovation targets.
- ▶ **Indoor Environmental Quality:** A mechanical ventilation system with heat recovery was installed, significantly improving indoor air quality and thermal comfort in all apartments.
- ▶ **Adaptation to Climate Change:** The introduction of renewable-based energy systems, passive envelope improvements, and lower operational energy use increased the building's resilience to temperature fluctuations and energy price volatility.
- ▶ **Climate Resilience of the Building:** By removing fossil fuel dependence and relying on renewable, locally generated energy, the building now operates with greater energy autonomy and reduced vulnerability to external supply risks.
- ▶ **Inclusion and Aesthetics:** The renovation preserved the historic façade and architectural details, maintaining the building's heritage character and contributing to urban identity and inclusiveness within Vienna's historic districts.
- ▶ **Other:** The project directly supported the City of Vienna's "Raus aus Gas" initiative, serving as a pilot case for fossil-fuel phase-out and large-scale decarbonization of historic multi-apartment buildings.

Trigger for Renovation

The renovation was primarily triggered by the need to phase out fossil gas systems and modernize the outdated energy infrastructure of a historic, gas-dependent residential building. Constructed around 1900, the property relied on individual gas boilers for heating and hot water and gas stoves for cooking, leading to high energy consumption and dependence on non-renewable sources.

The initiative was further driven by the owner's environmental and long-term vision to create a climate-friendly, future-oriented building, in line with Vienna's "Raus aus Gas" program promoting fossil-free, renewable-based energy systems. The project was also supported by public funding from the City of Vienna and national programs, which provided financial incentives for implementing a comprehensive thermal and energy renovation.

Specific Requirements, Challenges and Barriers

As a historic building, one major constraint was the need to preserve the architectural character and façade, which limited the possibility of external insulation. This required alternative solutions such as attic and basement insulation and efficiency improvements through internal measures.

Another key challenge was the complete removal of the gas infrastructure in an occupied multi-apartment building, which demanded careful coordination with residents and phased implementation to maintain habitability during the works.

Technical barriers included space limitations for installing the new central HP system and integrating it with existing distribution networks, as well as the structural and electrical adaptations required to accommodate new RES technologies such as the PV system.

Finally, ensuring compatibility between old and new components, meeting modern efficiency standards, and managing costs within available public funding frameworks added further complexity to the implementation process.

Reduction of whole-life-cycle greenhouse gas emissions	The project achieved a complete phase-out of fossil fuels, replacing all gas boilers and stoves with RES electricity-based systems. Operational emissions were reduced to near zero, contributing significantly to the reduction of whole-life-cycle GHG emissions. Additionally, RES and low-carbon materials (e.g., wood-fibre insulation) were used where possible, minimizing embodied carbon impacts.
Renewable energy sources	The renovation fully transitioned to RES energy, combining air-source HPs with an 18 kWp PV system for on-site renewable electricity production.
Data availability, accessibility and quality	The project included smart energy monitoring for real-time tracking of PV system generation, HP performance, and energy use. However, it does not explicitly reference open data sharing or structured data collection beyond operational monitoring.
Multiple benefits	Beyond emission reductions, the renovation delivered improved indoor comfort, air quality, lower operating costs, and heritage preservation, exemplifying a holistic approach to sustainable renovation.
Financing	The project successfully combined private investment with public funding from the City of Vienna, KPC, and Wohnfonds Wien. This blended financing model made deep renovation accessible to a private owner while showcasing the effectiveness of multi-level financial support mechanisms.

Implementation and stakeholders

The implementation of the Prechtlgasse 7 renovation was carried out as part of the City of Vienna’s “Raus aus Gas” initiative, in close collaboration between the building owner, technical planners, and public authorities. The process began with a feasibility study and energy concept, assessing options for phasing out gas and transitioning to RES. This was followed by detailed design and permitting, ensuring compliance with both heritage protection and EE requirements.

During the construction phase, the installation of the central HP system, PV system, and new energy distribution network was coordinated alongside thermal insulation improvements and electrical upgrades. Because the building was fully occupied, the renovation was implemented in phased stages, minimizing disruption to tenants and maintaining functionality throughout the process.

Close communication between the owner and the existing tenants was essential for the successful conversion to electric stoves and air-source HPs. This cooperation helped address concerns in advance and respond to individual needs during the renovation.

The key stakeholders included the private building owner, who initiated and financed the project with public support; the City of Vienna’s Environmental and Energy Department (MA 20), which provided funding and technical guidance; and Urban Innovation Vienna, which oversaw project coordination and documentation as part of the “Raus aus Gas” program. Additional contributors included architects, energy consultants, construction contractors, and technology suppliers for the HP and PV systems. This coordinated, multidisciplinary approach ensured that the renovation achieved both technical and sustainability objectives while preserving the building’s historic character.

Renovation Measures

The renovation of the Prechtlgasse 7 building combined comprehensive EE upgrades, RES integration, and architectural preservation to achieve a fully fossil-free, high-performance outcome.

► Energy efficiency measures:

To reduce thermal losses, the attic and basement ceilings were insulated using wood-fibre materials. The historic façade was preserved in accordance with heritage protection guidelines, meaning external insulation was not possible; instead, airtightness was improved through window repairs, resealing, and selective replacement. Rather than replacing all windows, only the panes of the existing 15-year-old windows were exchanged, upgrading them to triple glazing. For additional comfort and heat protection, the existing exterior blinds were renewed and supplemented as part of the façade improvement works.

A controlled mechanical ventilation system with heat recovery was installed to enhance indoor air quality and minimize ventilation-related heat losses. Furthermore, hydraulic balancing and smart control systems were implemented to optimize the heating distribution network and ensure efficient system operation.

► Renewable energy measures:

The building's entire heating infrastructure was modernized through the replacement of all individual gas boilers with a central low-temperature heating network powered by two air-source HPs (total capacity approx. 30 kW). The split system provides a dependable heat supply, even when one unit is undergoing maintenance. The existing radiators in the apartments can continue to be used after transition.

A rooftop PV system with an installed capacity of 18 kWp now provides renewable electricity to power the HPs and common building areas. To maintain a stable flow temperature of approximately 50 °C, a central 1,000-litre buffer tank was installed to optimize HP performance and system efficiency. In addition, 160-litre electric boilers were installed in each apartment to enable decentralized domestic hot water preparation. The renovation also included the replacement of all gas stoves with electric cooktops, completing the building's full transition to a fossil-free, all-electric energy supply.

► Other measures:

Additional interventions included the integration of a digital energy monitoring system that enables real-time tracking of energy flows, PV generation, and HP performance. Structural and electrical adjustments were carried out to accommodate the new systems within the historic building framework. The renovation was carefully phased to maintain occupancy, minimizing disruption for residents. Throughout the process, sustainable construction materials, such as wood-fibre insulation, were prioritized, and the building's historic façade and architectural details were preserved to maintain its cultural and aesthetic value within Vienna's protected urban fabric.

6.2 Financing

The financing of the Prechtlgasse 7 renovation project combined significant public grants with private investment from the building owner. The total renovation cost amounted to approx. €550,000, equivalent to about €750/m² of usable floor area. The project was supported by several national and regional funding programs, including:

- KPC-I ("Sanierungsscheck") – approx. €97,000 (approx. €130/m²)
- KPC-II ("Raus aus Öl & Gas") – approx. €50,000 (approx. €70/m²)
- KPC-III (PV) – approx. €6,500 (approx. €9/m²)
- Wohnfonds Wien – approx. €180,000 (approx. €250/m²)

KPC, short for "Kommunkredit Public Consulting", is the Austrian agency responsible for managing national environmental and EE subsidy programs, including "Sanierungsscheck" and "Raus aus Öl & Gas". In total, these

grants covered roughly 60% of the total renovation costs, with the remaining 40% financed privately by the building owner.

This financing structure represents a strong example of blended funding, where public incentives for energy transition and RES integration – under Vienna’s “Raus aus Gas” initiative – made deep renovation economically viable while reducing the owner’s financial burden. The key stakeholders included the building owner, who provided private co-financing; the City of Vienna through the Wohnfonds Wien program; and KPC, which administered the national grants for thermal renovation, renewable energy integration, and the “Raus aus Öl & Gas” transition scheme.

6.3 Sustainability Performance and KPIs

Sustainability has not been measured through established methods and models; however, the energy performance of the building has been documented before and after the renovation via metrics such as energy savings, heating demand reduction, and verified compliance with Austrian building energy standards. While no formal LCA was conducted, emission reductions can be estimated based on energy performance improvements (i.e., energy demand reduction by approx. 70 %) and fossil fuel phase-out which reduced the overall annual operational GHG emissions.

The following section provides an overview of the KPIs used to measure the renovation progress of the case study building. The indicators may rely on different approaches to value calculation, which are detailed in the last column.

Energy KPIs		
Energy savings per building	$Q_{H,nd,an} = 79.3 \text{ kWh}/(\text{m}^2\text{a})$ (71%) $E_{tot,del,an} = 134 \text{ MWh/a}$ (75%)	$Q_{H,nd,an}$ (before renovation) = 111.4 kWh/(m ² a) $Q_{H,nd,an}$ (after renovation) = 32.1 kWh/(m ² a) $E_{tot,del,an}$ (before renovation) = 246.9 kWh/(m ² a) $E_{tot,del,an}$ (after renovation) = 60.7 kWh/(m ² a)
Amount of primary energy saved	223 kWh/(m ² a) (82%)	$E_{Ptot,an}$ (before renovation) = 271.6 kWh/(m ² a) $E_{Ptot,an}$ (after renovation) = 48.6 kWh/(m ² a)
Share of energy from RES	45%	Based on delivered energy, the renewable share in primary energy is estimated at approx. 45%. After renovation, the building relies mainly on district heating (about 40% renewable share in Vienna) and on-site PV electricity (approx. 10% of delivered energy, fully renewable).
Energy from RES	18 kW installed	20 MWh produced
Environmental KPIs		
Annual operational GHG reduction	31.6 tCO ₂ /a (91%)	$M_{CO_2,an}$ (before renovation) = 34.9 tCO ₂ /a $M_{CO_2,an}$ (after renovation) = 3.3 tCO ₂ /a

6.4 Lessons Learned and Key Recommendations

The renovation of Prechtlgasse yielded several valuable lessons and recommendations for future fossil-free building projects.

- ▶ A key lesson learned was the effectiveness of combining thermal and technical modernization in a single, coordinated process. This integrated approach proved essential for achieving significant energy savings and a complete phase-out of fossil fuels.
- ▶ Another practical insight came from the acoustic assessment of the HP system, which confirmed compliance with local noise regulations but also recommended the use of “silent mode” operation or acoustic enclosures to further minimize sound emissions and ensure comfort for neighbouring residents.
- ▶ The project also demonstrated that deep renovations of occupied, heritage buildings can be executed efficiently within a relatively short timeframe – in this case, roughly two years from concept to commissioning – through careful planning and stakeholder coordination.

In terms of recommendations, the project team emphasized the importance of combining building envelope improvements with technical system upgrades, using high-performance insulation materials (with at least 25% renewable content) and air-source HPs as the preferred RES.

Finally, the case highlighted the critical role of public funding alignment, showing that tailoring design and renovation choices to meet the eligibility criteria of Vienna’s and federal KPC funding programs can make ambitious, fossil-free retrofits both technically and economically feasible.

7 | CS6 – AUT – Residential building – Single-family house

7.1 Case Study Building Overview

Building Description

This case study examines the renovation of a SFH located in Graz, Austria. Before the renovation, the building was in need of modernization to improve its energy performance and living comfort. It suffered from poor insulation on the walls and roof, outdated windows, and an inefficient heating system based on conventional energy sources. The interior layout and usable living space were limited, and the overall energy performance fell short of modern efficiency standards. These conditions prompted the new owner to undertake a deep renovation aimed at enhancing thermal comfort, reducing energy consumption, and expanding the living area.

Originally built in 1970 with hollow brick walls and a reinforced concrete structure topped by a wooden ceiling, the property included two upper floors and a basement, totaling 172.2 m² gross area and 137.7 m² of heated space. The renovation transformed the basement into habitable space and added an attached apartment, increasing the total area to 256.1 m² and heated space to 204.9 m². The house was redesigned to accommodate five residents, now featuring four bedrooms, two bathrooms, an additional toilet, an open kitchen-living area, a storage room, a technical room, and a garage. The new separate apartment includes a bedroom, kitchen, bathroom, and living space.

Although extensive structural repairs were necessary, seismic safety was not a concern due to the low regional risk. Special focus was placed on deep thermal renovation measures that substantially improved the building's energy performance. The EPC rating for heating energy demand improved markedly from class F to B, while the primary energy demand rating rose from class F to A++, meeting near zero energy building standards. These upgrades significantly enhanced both living comfort and energy efficiency, demonstrating a successful example of comprehensive residential building renovation.

Key Building Data	
Building classification	Residential building – Single-family house
Renovation scale	Building
Target group	Building owners, indirectly also public administrations and financial institutions
Number of buildings	1
Building age	Built in 1970; 55 years
Location	Graz, Austria
Short building description	Single-family house with poor insulation, outdated windows, and an inefficient heating system, resulting in low energy performance and limited comfort.

Renovation Indicators

Total floor area	172.2 m ²
Renovated floor area	172.2 m ² + extension (total 256.1 m ²)
Masonry walls strengthened	Fundament
PV system	15,6 kWp PV system

Renovation Measures

Energy	• Comprehensive deep renovation. • Exchange of heating system, from direct electrical heating and hot water systems to a geothermal HP. • Addition of under-floor heating. • Insulation of the roof (waterproofing, reuse of existing roof insulation + addition). • Insulation of the walls (XPS). • Replacement of windows.
Seismic Resilience	
Renewable Energy	• Heating system exchange (geothermal HP + under-floor heating). • PV plant installation.
Other Measures	• Structural reinforcement of the fundament, not related to seismic strengthening of the building. • Extension of the building, attached apartment.

Pictures



Goals of the Renovation

The goal of the renovation was to deeply modernize a SFH to significantly improve its energy performance while also expanding and upgrading the living space. The project was initiated after a change of ownership, with the new owner aiming to enhance both the comfort and efficiency of the home through a comprehensive renovation approach.

The renovation addressed several key aspects, including ZEB and MEPS compliance, the development of a Renovation Passport and EPCs, as well as adaptation to climate change, enhanced climate resilience, and the improvement of the building's inclusiveness and aesthetics.

Trigger for Renovation

The renovation was triggered by a change of ownership and the new owner's desire to improve comfort and modernize the living environment.

Specific Requirements, Challenges and Barriers

The renovation aimed to meet nZEB standards, but its implementation faced several challenges, including high renovation costs, technical hurdles during construction, and bureaucratic barriers in accessing grant funding.

Through the renovation several key challenges were addressed, such as the reduction of whole life-cycle GHG emissions, the integration of RES, and improvements in data availability, accessibility, and quality, while also tackling financing barriers. In relation to MEPS, the renovation contributed to the improvement of worst-performing buildings, defined the appropriate renovation type, and incorporated monitoring measures to ensure long-term performance verification.

Implementation and stakeholders

The implementation process was carried out directly with the owner and investor, who oversaw and coordinated all renovation activities and decisions throughout the project.

Renovation Measures

The renovation involved a deep retrofit of a SFH to improve energy performance and expand the living area. Key measures included the replacement of the heating system with a HP and the installation of floor heating, as well as the addition of solar panels to increase the share of RES. The walls and roof were insulated with XPS insulation, reusing the existing roof insulation where possible, and all windows were replaced to enhance airtightness and thermal comfort.

7.2 Financing

The total eligible investment costs for the renovation amounted to €221,748, including €20,616 for the installation of a 15,6 kWp PV system and €201,132 for the deep renovation works, which covered the installation of a HP, floor heating, geothermal system (204 linear meters), as well as upgrades to windows, façade, attic insulation, flooring, and window reveals.

The project was financed through a combination of private investment, government grants, and a soft renovation loan (“Baukonto”)¹. The “Baukonto”, amounting to €113,853, provided flexible interim financing with a variable interest rate, supported by an underlying guarantee instrument secured through a land registry mortgage set 20–50% below market value. Additional public grants amounted to €107,895 and were awarded to support EE measures and RES integration. This blended financing approach enabled the investor to implement a deep renovation while maintaining financial stability and access to affordable credit.

The key stakeholders involved in the financing of the renovation were the private building owner and investor, who initiated and co-financed the project, and the financial institutions that provided the renovation loan and related guarantee instruments. In addition, public authorities played a supporting role by offering grants and subsidies to promote EE renovation measures.

7.3 Sustainability Performance and KPIs

The sustainability performance of the renovation was evaluated using BIM for design coordination, the EPC to quantify EE improvements, and LCA together with Whole Life Carbon calculations to assess both operational and embodied emissions. These methods provided a comprehensive view of the project’s environmental and energy performance.

Energy KPIs		
Energy savings per building	$Q_{H,nd,an} = 166,4 \text{ kWh/m}^2$ (82%) $E_{tot,del,an} = 27.14 \text{ MWh/a}$ (90%)	$Q_{H,nd,an}$ (before renovation) = 204.1 kWh/(m ² a) $Q_{H,nd,an}$ (after renovation) = 37.7 kWh/(m ² a) $E_{tot,del,an}$ (before renovation) = 232.1 kWh/(m ² a) $E_{tot,del,an}$ (after renovation) = 23.5 kWh/(m ² a)
Amount of primary energy saved	491.6 kWh/m ² (86%)	$E_{Ptot,an}$ (before renovation) = 542.7 kWh/(m ² a) $E_{Ptot,an}$ (after renovation) = 51.1 kWh/(m ² a)
Share of energy from RES	100%	$E_{Pren,an}/E_{Ptot,an}$
Energy from RES	15.6 kWp installed	10,249 kWh/a generated
Environmental KPIs		
Annual operational GHG reduction	5.86 tCO ₂ /a (96%)	$M_{CO_2,an}$ (before renovation) = 6.09 tCO ₂ /a $M_{CO_2,an}$ (after renovation) = 0.23 tCO ₂ /a

¹ The “Wohnbaukonto” (also known as “Baukonto” or building account) is a specialized financial instrument used in Austria to manage and finance renovation or construction projects. It functions as a dedicated project account, where all payments related to the renovation – such as contractor invoices, material purchases, and received subsidies – are processed transparently. The account typically includes a credit line (“Rahmenkredit”) that provides interim or bridging financing, allowing the owner to access funds flexibly during construction before the main loan or mortgage is fully disbursed. Interest is only charged on the amount actually drawn, not on the entire credit limit, which helps maintain liquidity throughout different project phases. After completion, the “Wohnbaukonto” is usually converted into a long-term mortgage or closed once the project is settled. This setup offers a flexible and transparent financing solution that supports smooth cash flow management during renovation works.

7.4 Lessons Learned and Key Recommendations

The renovation process in Styria revealed several important lessons regarding the financial, technical, and administrative barriers that continue to hinder broader adoption of deep renovation.

- ▶ One major lesson was that mandatory energy audits and renovation planning, though essential prerequisites for obtaining grants, are not considered eligible costs, forcing owners to cover them out of pocket.
- ▶ Similarly, numerous hidden expenses emerged, as qualitative renovation works – such as using aluminium window frames instead of cheaper plastic ones – were often ineligible for subsidies, even when they provided higher performance or durability.
- ▶ Another key challenge was the complex coordination of renovation works, which required ongoing monitoring and strong project management to avoid delays or quality issues.
- ▶ The process of applying for grants also proved highly cumbersome. The absence of a One-Stop-Shop (OSS) for renovation support in Styria made grant searches and submissions lengthy and complex, discouraging many property owners.
- ▶ Use of the “Baukonto”¹ financing model which offered flexibility during construction period. This is typically followed by a standard loan.

In general, high renovation costs, procedural hurdles, and technical risks made renovation appear less predictable than new construction, even though building new is usually more expensive. Compounding these challenges was the limited availability of skilled and reliable labour, which continues to be a major barrier to scaling up quality renovations.

To address these issues, it is recommended to establish an OSS in Styria and across all Austrian federal states, following the Viennese example of “Hauskunft”² operated by “wohnfonds_wien” in order to streamline administrative processes and directly connect homeowners with certified renovation companies and financial advisors. Additionally, introducing grant mechanisms through VAT deductions (currently 20% in Austria) could significantly reduce financial barriers and administrative burdens, making deep renovations more accessible and attractive for private owners. These measures would help accelerate the regional transition toward a more energy-efficient and climate-resilient building stock.

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² “Hauskunft” is a OSS for building renovation in Vienna, set up as part of the EU-funded RenoBooster project. It provides free, independent, and individualized advice and support for private homeowners, guiding them through the entire renovation process—from initial consideration to quality assurance after completion. The centre offers orientation, on-site building checks (for single or multi-dwelling houses), and tailored counselling on developing financed refurbishment plans.

8 | CS7 – SI – Public building – primary school

8.1 Case study building overview

Building Description

Vodmat Primary School is a reinforced concrete building located in Ljubljana, Slovenia, designed by architect Emil Navinšek and protected as a cultural heritage site under the national Institute for the Protection of Cultural Heritage (ZVKDS). The school complex includes two gymnasiums (a large and a small one) and the main school building. Prior to renovation, the structure exhibited poor energy performance, outdated installations, and limited fire and seismic safety, while maintaining significant architectural value.

The complex was built in 1965, with an extension added in 1977, and underwent a comprehensive structural and energy renovation in 2019. The school belongs to the category Buildings for education and research (CC-SI 12630).

Key Building Data	
Building classification	Public building – primary school
Renovation scale	Building-level
Target group	Public school administration
Number of buildings	1
Building age	Built in 1965; 60 years
Location	Ljubljana, Slovenia
Short building description	Reinforced concrete and brick school complex with flat roofs and insulated façades; built in 1965, extended in 1977, comprehensively renovated in 2019.
Renovation Indicators	
Total floor area	4,678 m ²
Renovated floor area	4,678 m ²
Masonry walls strengthened	2,165 m ²
PV system	/

Renovation Measures

Energy

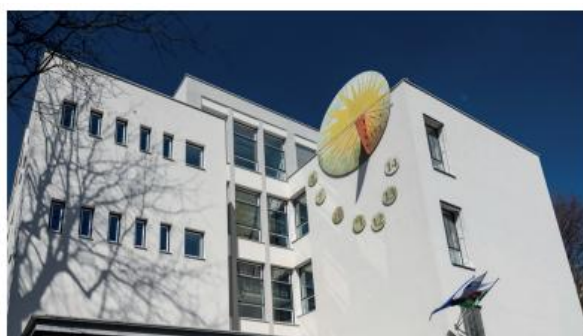
- The building underwent a comprehensive energy renovation in 2019 as part of a broader seismic and safety upgrade of the Vodmat Primary School complex.
- Building envelope improvements included 16 cm mineral wool façade insulation (12 cm on the large gym), 16 cm XPS basement wall insulation, and 6 cm XPS + 20 cm EPS roof insulation (up to 26 cm in total).
- New PVC/ALU windows and doors were installed with $U_{win} = 1.10\text{--}1.30$ W/m²K (windows) and $U_{doors} = 1.60$ W/m²K, significantly improving thermal performance.
- Heating system modernization included renewal of the district heating substation, installation of thermostatic radiator valves, hydraulic balancing, and introduction of energy metering and monitoring.
- Ventilation systems were replaced with high-efficiency units featuring > 73 % heat recovery and automatic control for gyms, sanitary areas, and basement spaces.
- Lighting was fully replaced with LED luminaires (approx. 500 units), with automatic switching and daylight optimization.
- A central energy management system (EMS) was introduced to monitor real-time energy use and evaluate renovation performance.

Seismic Resilience

- The 2019 renovation included a comprehensive seismic strengthening of the existing reinforced concrete and masonry structure, designed to meet current Slovenian and Eurocode seismic safety standards.
- Additional reinforced concrete shear walls were introduced in the older sections of the building to improve horizontal stiffness and reduce lateral displacement during seismic events.
- Steel frames were installed in key structural zones to strengthen load-bearing capacity and connect structural elements across different building wings.
- Reinforced plaster layers were applied on selected walls to increase ductility and prevent brittle failures.
- Structural interventions were carefully designed to preserve the building's heritage-protected façade and architectural features.
- Seismic retrofitting was integrated with energy renovation works to optimize cost, scheduling, and material efficiency.
- Post-renovation, the building's seismic performance and safety level were significantly enhanced, ensuring compliance with national building regulations and improving resilience against moderate to strong earthquakes.

Renewable Energy	• The school's heating and domestic hot water are supplied through the district heating network, which includes a share of renewable and waste heat sources, representing approx. 31 % renewable primary energy according to the energy certificate. • The renovation focused on reducing overall energy demand to improve compatibility with future RES integration (e.g., PV system or solar thermal collectors). • Technical provisions for future PV system installation were included during the renovation (roof insulation and structure prepared for load capacity and wiring routes). • The design strategy ensures that the building's energy systems remain compatible with nZEB and RES integration objectives defined in national long-term renovation plans.
Other Measures	• Fire safety improvements included installation of an external fire escape staircase, a fire detection and alarm system, and creation of additional fire compartments to meet regulatory standards. • A radon ventilation system was installed to reduce indoor radon concentration and improve air quality. • Electrical installations were completely replaced, improving operational safety and readiness for digital monitoring. • Interior equipment and furnishings were upgraded to enhance functionality and comfort for students and staff. • The renovation was carried out under a public-private partnership (PPP) model, combining municipal and private financing and serving as a replicable model for integrated energy, seismic, and safety renovation of public buildings.

Pictures



Goals of the Renovation

The renovation aimed to enhance the safety, comfort, and energy performance of the school while preserving its architectural heritage. The key objectives included:

- ▶ Improving **energy efficiency** and reducing GHG emissions;
- ▶ Strengthening **seismic resilience** to meet current safety standards;
- ▶ Upgrading **fire protection** and **indoor air quality** (radon reduction);
- ▶ Modernizing **building systems** (heating, ventilation, lighting, monitoring);

- ▶ Demonstrating a **comprehensive renovation model** within a PPP framework.

Trigger for Renovation

The renovation was triggered by the need to address the building's **poor energy performance** and **structural vulnerability to earthquakes**, as well as to **ensure user safety** and **compliance with modern energy and safety regulations**. The project also aimed to set a precedent for combining seismic strengthening and energy renovation in heritage-protected educational buildings.

Specific Requirements, Challenges and Barriers

Key challenges included:

- ▶ Ensuring full **compliance with cultural heritage protection guidelines**, requiring close coordination with ZVKDS;
- ▶ **Integrating seismic strengthening measures** without compromising the building's architectural integrity;
- ▶ Managing the **complexity of works in an operational school environment**;
- ▶ Structuring the **financial model under a PPP** to mobilize investment;
- ▶ Achieving balance between **cost-efficiency**, **heritage conservation**, and **modern technical standards**.

Implementation and stakeholders

The project was implemented through a **PPP** between the **Municipality of Ljubljana** and a consortium of private partners: **Petrol**, **Resalta**, and **Javna Razsvetljava**.

- ▶ The **municipality** acted as the project owner and contracting authority;
- ▶ The **PPP consortium** was responsible for design, implementation, and financing;
- ▶ The **Institute for the Protection of Cultural Heritage (ZVKDS)** provided oversight and approvals;
- ▶ **Local contractors and technical experts** carried out the construction and system installations. The implementation followed a design-and-build model with continuous supervision, allowing adjustments to ensure compliance with both energy and heritage requirements.

Renovation Measures

The comprehensive renovation included:

- ▶ **Building envelope:** External wall insulation, roof insulation, façade renovation;
- ▶ **Windows and doors:** Replacement with energy-efficient units and external shading;
- ▶ **Heating system:** New thermostatic valves, radiator replacement, hydraulic balancing, upgraded heat substation;
- ▶ **Ventilation:** New high-efficiency mechanical ventilation with 73% heat recovery and radon reduction system;
- ▶ **Lighting:** Replacement of approx. 500 fixtures with LED technology;
- ▶ **Fire safety:** New fire detection system, external staircase, and fire compartments;
- ▶ **Structural strengthening:** Reinforced concrete walls, steel frames, and plaster strengthening;
- ▶ **Energy management:** Central monitoring system for real-time performance tracking.

The building has a reinforced concrete and brick structural system, with 40 cm brick walls (main part) and 20 cm for the large gymnasium. The external walls are insulated with 16 cm of mineral wool, or 12 cm in parts of the

gymnasium. The basement wall is insulated with 16 cm XPS, and the floors on ground level have layers of waterproofing, insulation (10 cm EPS), and screed according to room use. Roofs are flat reinforced concrete slabs insulated with 6 cm XPS + 20 cm EPS (main school), 13 + 10 cm EPS (small gym), and 20 cm mineral wool (large gym).

The façade is finished with a thin-layer plaster system. Windows and doors were replaced with PVC and aluminium units ($U_w = 1.10\text{--}1.30 \text{ W/m}^2\text{K}$, $U_d = 1.60 \text{ W/m}^2\text{K}$). Heating and domestic hot water are supplied via district heating, and ventilation systems are installed in the gyms, basement, third floor, and sanitary areas, controlled by an automatic regulation system.

Based on dynamic-static analyses carried out in accordance with the Eurocode 8 (EC8) standards, a comprehensive seismic strengthening of the building structure was implemented. Reinforcements were adapted to the specific parts of the building. In the taller section, new reinforced concrete (RC) walls were constructed through all floors, and in some areas, existing walls were strengthened with double-sided reinforcement and concrete jacketing. In the basement of the taller part, existing foundations were widened in selected locations.

The new RC walls were installed either adjacent to existing walls or in places where masonry walls had been previously removed. The structure of the small gymnasium and locker rooms was strengthened with a combination of new RC walls in the gym and fiber-reinforced cement plasters (FRG) applied to the locker room walls. In the locker room area of the large gymnasium, seismic strengthening included FRG coatings on existing masonry walls and the construction of new, thicker masonry walls further reinforced with FRG layers.

To support these new walls, additional RC basement walls and foundations were built beneath them. Overall, these interventions substantially increased the building's lateral stiffness, ductility, and seismic resistance, ensuring compliance with current seismic safety requirements.

8.2 Financing

The comprehensive renovation of Vodmat Primary School was implemented under the Energy Performance Contracting (EnPC) framework as part of the Energy Rehabilitation of Public Buildings – Phase 2 (EOL-2) programme, coordinated by the Municipality of Ljubljana. This large-scale municipal programme aimed to upgrade EE and safety standards across several public buildings through PPP and ESCO-based financing models.

The total investment cost of the renovation amounted to approx. €3.6 million (excluding VAT), of which:

- ▶ €1,253,000 was dedicated to energy renovation measures (building envelope, HVAC, lighting, control systems),
- ▶ €650,000 was allocated for seismic strengthening, and
- ▶ the remainder covered fire safety, radon mitigation, electrical installations, and interior refurbishment.

The energy renovation was co-financed by a 40 % grant from national and EU cohesion funds through the EOL-2 programme, while the remaining 60 % was financed by the private partner through the ESCO model. Under this arrangement, the ESCO consortium (Petrol, Resalta, and Javna Razsvetljava) provided up-front investment capital, implemented the renovation works, and assumed performance risk related to guaranteed energy savings.

The PPP structure enabled the Municipality of Ljubljana to renovate the building without immediate public budget expenditure, as repayment to the ESCO was based on verified energy cost savings over the contract duration. The ESCO partner also committed to operation and maintenance of the installed systems, continuous energy monitoring, and achievement of the contractual performance indicators.

This integrated financial model successfully combined grant funding, private capital, and performance-based repayment, ensuring both the technical and financial sustainability of the project. It represents a replicable approach for municipalities seeking to couple EE improvements with seismic and safety upgrades in public buildings.

8.3 Sustainability Performance and KPIs

Energy KPIs		
Energy savings per building	$Q_{H,nd,an} = 68.6 \text{ kWh/m}^2$ (61%) $E_{tot,del,an} = 320.4 \text{ MWh/a}$ (47%)	$Q_{H,nd,an}$ (before renovation) = 112.2 kWh/(m ² a) $Q_{H,nd,an}$ (after renovation) = 43.6 kWh/(m ² a) $E_{tot,del,an}$ (before renovation) = 144.5 kWh/(m ² a) $E_{tot,del,an}$ (after renovation) = 76.0 kWh/(m ² a)
Amount of primary energy saved	54 kWh/m ² (42%)	$E_{Ptot,an}$ (before renovation) = 130 kWh/(m ² a) $E_{Ptot,an}$ (after renovation) = 76 kWh/(m ² a)
Share of energy from RES	31%	$E_{Pren,an}/E_{Ptot,an}$; based on district heating network
Energy from RES	/	/
Environmental KPIs		
Annual operational GHG reduction	97 tCO ₂ /a (47%)	$M_{CO_2,an}$ (before renovation) = 204.6 tCO ₂ /a $M_{CO_2,an}$ (after renovation) = 107.6 tCO ₂ /a
Seismic Resilience KPIs		
Seismic safety index	<i>missing</i>	A formal seismic safety index was not calculated, as the available structural documentation did not include a full EC8-compliant analysis.
Walls strengthening	2,165 m ²	Strengthening measures were implemented based on a dedicated structural project, including reinforcement of approx. 2,165 m ² of walls. The intervention qualitatively improved seismic resistance, although quantitative verification was not performed.

8.4 Lessons Learned and Key Recommendations

The renovation of Vodmat Primary School demonstrated that integrated projects combining EE, seismic safety, and heritage protection are technically feasible and financially viable when supported by an appropriate contractual and financing framework. A key lesson learned is that the PPP and EnPC models can effectively mobilize private capital for public infrastructure renewal, provided that performance guarantees and transparent monitoring mechanisms are in place. The combination of grant support for energy measures and ESCO financing ensured project bankability and long-term sustainability, reducing the financial burden on the municipality.

From a technical perspective, the project showed that energy and structural retrofitting can be successfully coordinated within a single intervention. However, this requires precise planning and sequencing of works,

especially in heritage-protected and operational buildings, where construction phasing must minimize disruption to users. The use of dynamic structural analysis (EC8) and advanced design coordination between architectural, structural, and MEP disciplines proved essential to achieve both seismic safety and high energy performance without compromising the building's architectural integrity.

In terms of implementation, the project confirmed the importance of close collaboration among stakeholders—the municipality, ESCO partners, designers, contractors, and heritage authorities. Early-stage alignment on technical standards, procurement procedures, and data collection for performance verification was crucial for efficient execution and later monitoring under the EnPC contract. The integration of an energy management system provided reliable data for assessing savings, validating contractual obligations, and informing future municipal renovation programmes.

Key recommendations include promoting integrated renovation planning that addresses structural, energy, and safety aspects from the outset; strengthening municipal capacities to manage PPP/EnPC contracts; and ensuring that national programmes such as EOL-type schemes continue to provide blended financing for deep renovations. Future projects should also enhance post-renovation monitoring frameworks, capturing not only energy savings but also the added value of improved seismic resilience, indoor comfort, and heritage preservation.

Commentary – Structural (Seismic) Renovation Domain

The documentation reviewed for the seismic renovation of Vodmat Primary School reveals an important systemic issue. Although the technical report refers to dynamic “push-over” analyses and structural calculations following the principles of Eurocode 8 (EC8), it does not explicitly confirm full compliance with EC8 standards, nor does it demonstrate verification against all relevant limit states defined therein. The absence of a clear conformity statement—despite the document being signed by a licensed engineer—suggests that current regulatory and procedural frameworks may allow partial or simplified structural assessments to be treated as sufficient for building permits.

This case illustrates a broader structural governance gap: while energy renovation projects are strongly incentivized and systematically implemented (often driven by grant availability and EU obligations), the seismic safety component remains under-regulated and less stringently verified in Slovenia. The legislation appears to permit “adequate” rather than “comprehensive” seismic design, which may not ensure the resilience expected under modern European standards, especially for critical public buildings such as schools.

The experience from this project reinforces the need to align national design and verification procedures with Eurocode-based seismic assessment methodologies, ensuring that every structural intervention accompanying an energy renovation truly enhances safety and long-term resilience. Integrated renovation should therefore be encouraged—but not pursued at any cost. Where energy funding drives implementation, it must be accompanied by consistent structural quality assurance, otherwise the opportunity to upgrade safety alongside efficiency is only partially realized.

9 | CS8 – SI – Public building – Educational and healthcare buildings

9.1 Case study building overview

Building Description

The Institute for the Deaf and Hard of Hearing Ljubljana (Zavod za gluhe in naglušne Ljubljana – ZGNL) is a public educational and rehabilitation complex located at Vojkova cesta 74, Ljubljana. The facility comprises 2 interconnected buildings (A1–B6), constructed 1950 and 1980, with a total gross floor area of approx. 7,039 m².

The complex accommodates educational, therapeutic, residential, and administrative functions and serves children, youth, and adults with hearing and speech impairments. Prior to renovation, the buildings exhibited high energy consumption, obsolete systems, and insufficient seismic resistance, typical for older masonry and reinforced-concrete structures.

Key Building Data	
Building classification	Public building – Educational and healthcare buildings
Renovation scale	Building-level
Target group	Public school administration
Number of buildings	2
Building age	Built between 1950 and 1980 (multiple construction phases and typologies); between 45–75 years
Location	Ljubljana, Slovenia
Short building description	Multi-building educational and rehabilitation complex with reinforced concrete and masonry structures, flat roofs, and mixed façades; used for schooling, therapy, accommodation, and administration; total floor area 7,039 m ² .
Renovation Indicators	
Total floor area	7,039 m ²
Renovated floor area	7,039 m ²
Masonry walls strengthened	3,875 m ²
PV system	/

Renovation Measures

Energy

- Comprehensive thermal insulation of façades and roofs; replacement of windows and doors with high-performance units.
- New HVAC and mechanical ventilation with heat recovery installed in main buildings.
- Full LED lighting retrofit and introduction of a digital Building Management System (BMS).
- Energy monitoring integrated to track performance and ensure nZEB compliance.

Seismic Resilience

- Structural reinforcement of all main buildings using new RC shear walls and frames.
- FRG (fiber-reinforced grout) coatings applied to existing masonry walls.
- Foundation strengthening and structural connection improvements between wings.
- Design based on EC8 dynamic analysis to enhance earthquake resistance and safety.

Renewable Energy

Other Measures

Pictures



Goals of the Renovation

The renovation aimed to transform the ZGNL complex into a safe, energy-efficient, and functionally modern educational and healthcare facility. The main goals included:

- ▶ Achieving deep energy renovation and compliance with nZEB standards;
- ▶ Improving seismic stability and structural safety;
- ▶ Upgrading indoor comfort and accessibility for vulnerable users;
- ▶ Enhancing fire safety and functional organization of the premises;
- ▶ Demonstrating the integration of energy, seismic, and functional upgrades within a public-sector investment supported by the National Recovery and Resilience Plan (NRRP).

Trigger for Renovation

The primary trigger was the poor technical and energy condition of the existing buildings, coupled with the need to improve seismic safety and modernize facilities for inclusive education and healthcare. The renovation was initiated under the NRRP (Component C1 – K2: Sustainable Renovation of Buildings), leveraging EU funds to accelerate deep renovation of public educational institutions.

Specific Requirements, Challenges and Barriers

- ▶ The building serves users with hearing and communication impairments, requiring careful planning to ensure safety, accessibility, and uninterrupted operation during construction.
- ▶ The multi-building layout with differing structural systems and construction periods posed challenges for uniform energy and seismic upgrading.
- ▶ The project demanded full compliance with heritage and public procurement procedures under NRRP rules, including strict cost control and reporting.
- ▶ Coordination of energy, seismic, and architectural interventions within an occupied, operational facility required advanced scheduling and phased implementation.
- ▶ The introduction of modern ventilation and automation systems had to be adapted to the constraints of existing structures and limited ceiling height

Implementation and stakeholders

The project is implemented under the NRRP, coordinated by the Ministry of the Environment, Climate and Energy (MECE) and financed by the EU Recovery and Resilience Facility (RRF).

- ▶ Client / Investor: Zavod za gluhe in naglušne Ljubljana (ZGNL)
- ▶ Financing Authority: Ministry of Environment, Climate and Energy (MECE) / EU RRF
- ▶ Designers: consortium of structural, MEP, and architectural engineers (DGD and PZI stages)
- ▶ Contractor: VG5 d.o.o. (lead construction company)
- ▶ Supervision: authorized engineering supervision in accordance with Slovenian Construction Act (GZ-1) Implementation began in 2024 and follows a design–bid–build model, with sequential phases addressing energy renovation, structural strengthening, and functional adaptation. The project’s total value is estimated at €6.0 million (incl. VAT).

Renovation Measures

- ▶ Energy efficiency: façade and roof insulation, replacement of windows and doors, installation of new energy-efficient HVAC and ventilation systems with heat recovery, LED lighting, and energy monitoring.
- ▶ Structural (seismic) strengthening: addition of reinforced-concrete shear walls and frames, FRG (fiber-reinforced grout) coatings on masonry walls, and foundation improvements.
- ▶ Building systems: replacement of electrical installations, modernization of heating and hot water systems, and introduction of building automation.
- ▶ Fire safety: upgraded alarm systems, fire compartments, and improved evacuation routes.
- ▶ Functional and accessibility improvements: interior reorganization for educational and rehabilitation activities, barrier-free access, and improved indoor air quality.

9.2 Financing

The renovation of the Institute for the Deaf and Hard of Hearing Ljubljana (ZGNL) is financed entirely through public funding under the Slovenian NRRP, Component C1.K2: Sustainable Renovation of Buildings. The total investment value amounts to approx. €6.0 million (including VAT).

The project's financing is structured as follows:

- ▶ EU funding (RRF): approx. EU 85 % of total eligible costs, provided through the MECE;
- ▶ National co-financing (Republic of Slovenia): approx. 15 % of total costs, covering the remaining portion of eligible expenditure;
- ▶ Own contribution of the institution (ZGNL): limited to non-eligible minor costs (furniture, small equipment, etc.), covered from institutional or municipal resources.

The beneficiary and contracting authority is ZGNL Ljubljana, which oversees the full investment, procurement, and reporting in accordance with NRRP requirements. Project implementation, monitoring, and financial control are supervised by the MECE and the Government Office for Development and EU Cohesion Policy (SVRK).

The financing model follows a design–bid–build (DBB) approach typical for NRRP projects. All works and supplies are publicly procured under the Slovenian Public Procurement Act (ZJN-3). Payments are made based on verified progress and completion milestones, subject to technical and administrative audits at national and EU levels.

Unlike earlier PPP-based municipal programmes (e.g., EOL), the ZGNL project is fully publicly financed, with no private investment or performance-based repayment mechanisms. This structure allows full ownership and long-term asset management by the institution while ensuring compliance with sustainability and energy performance requirements of the NRRP.

9.3 Sustainability Performance and KPIs

Energy KPIs		
Energy savings per building	$Q_{H,nd,an} = 98 \text{ kWh/m}^2$ (69%) $E_{tot,del,an} = 509 \text{ MWh/a}$ (58%)	$Q_{H,nd,an}$ (before renovation) = 142 kWh/(m ² a) $Q_{H,nd,an}$ (after renovation) = 44 kWh/(m ² a) $E_{tot,del,an}$ (before renovation) = 185 kWh/(m ² a) $E_{tot,del,an}$ (after renovation) = 76 kWh/(m ² a)
Amount of primary energy saved	167 kWh/(m ² a) (77%)	$E_{Ptot,an}$ (before renovation) = 221 kWh/(m ² a) $E_{Ptot,an}$ (after renovation) = 54 kWh/(m ² a)
Share of energy from RES	31%	$E_{Pren,an}/E_{Ptot,an}$; based on district heating network
Energy from RES	0 kW installed	
Environmental KPIs		
Annual operational GHG reduction	312 tCO ₂ /a (82%)	$M_{CO_2,an}$ (before renovation) = 380 tCO ₂ /a $M_{CO_2,an}$ (after renovation) = 68 tCO ₂ /a
Seismic Resilience KPIs		
Seismic safety index	<i>missing</i>	A formal seismic safety index was not calculated, as the available structural documentation did not include a full EC8-compliant analysis.
Walls strengthening	3,875 m ²	Strengthening measures were implemented based on a dedicated structural project, including reinforcement of approx. 2,165 m ² of walls. The intervention qualitatively improved seismic resistance, although quantitative verification was not performed.

9.4 Lessons Learned and Key Recommendations

The renovation of the Institute for the Deaf and Hard of Hearing Ljubljana (ZGNL) offers valuable insights into the implementation of large-scale, publicly financed deep renovations that combine energy, seismic, and functional upgrades in complex institutional settings.

A key lesson learned is that integrated project planning—bringing together EE, structural safety, and accessibility from the earliest design stage—is essential for successful implementation. The project involved several structurally and functionally diverse buildings, which required tailored technical solutions and coordinated sequencing of works. Close collaboration between architectural, structural, and MEP engineers was crucial to avoid conflicts between seismic strengthening and energy performance measures.

Another major takeaway is that renovations in special-education institutions demand additional sensitivity and adaptability. Construction works had to be carefully phased to minimize disruption to educational and therapeutic activities, while ensuring the safety and comfort of users with hearing and communication

impairments. This experience underlines the importance of user-centered design and stakeholder communication, especially in facilities serving vulnerable populations.

From a financial and administrative perspective, the ZGNL project confirmed the effectiveness of direct public funding under the NRRP. Unlike PPP or ESCO schemes, this model provides more flexibility for deep, multi-dimensional renovations where return on investment cannot be easily monetized. However, it also demonstrated the high administrative burden and reporting complexity associated with NRRP procedures, which may delay implementation if not supported by sufficient institutional capacity.

Key recommendations include:

- ▶ Future renovation programmes should institutionalize integrated design methodologies, ensuring that energy and seismic aspects are treated jointly, not sequentially.
- ▶ For buildings serving vulnerable users, accessibility, indoor comfort, and safety must be elevated to the same level of importance as EE.
- ▶ Capacity-building for public institutions (beneficiaries) is essential to manage NRRP-level administrative requirements efficiently.
- ▶ The monitoring and evaluation framework for such projects should extend beyond energy KPIs to include seismic resilience, functional usability, and social co-benefits.
- ▶ Finally, sustainable renovation policies should encourage replicability through open knowledge exchange, so that lessons from complex cases like ZGNL can inform future integrated renovation strategies in the public sector.

10 | CS9 – SI – Residential building – semi-detached residential building

10.1 Case Study Building Overview

Building Description

The presented case study concerns a semi-detached residential building located in Ljubljana, Slovenia, originally constructed in 1975. The renovation was carried out between 2021 and 2023 and included only one dwelling unit of the two-family house.

The comprehensive renovation aimed to achieve the nearly zero-energy building standard, improve indoor comfort, and significantly reduce energy consumption. The energy retrofit was implemented in line with the Eco fund's requirements for deep renovation.

Main measures included a complete thermal insulation of the building envelope, replacement of windows and doors, installation of a central mechanical ventilation system with heat recovery, HP for space heating and domestic hot water, and a rooftop photovoltaic system (11 kW).

The total heated floor area of the renovated part is 186 m², distributed across three storeys. The investment in the energy renovation amounted to €86,000, partially co-financed by the Eco fund's grant of €28,500, with the remainder covered by private funds.

Key Building Data	
Building classification	Residential building – semi-detached residential building (single dwelling unit renovated)
Renovation scale	Building
Target group	Building owners
Number of buildings	1
Building age	Built in 1975; 50 years old
Location	Ljubljana, Slovenia
Short building description	Residential apartment building
Renovation Indicators	
Total floor area	186 m ²
Renovated floor area	186 m ²
Masonry walls strengthened	/
PV system	11 kW

Renovation Measures

Energy	Comprehensive thermal insulation of all envelope elements, replacement of windows and doors and installation of central ventilation with heat recovery.
Seismic Resilience	/
Renewable Energy	- Replacement of old fuel oil boiler with heat pump air-water. - Installation of an 11kW rooftop PV system for on-site electricity generation.
Other Measures	Complete modernization of internal installations and building automation; focus on indoor comfort, airtightness, and compliance with Eco fund's nZEB requirements.

Pictures



Goals of the Renovation

The main goals were to achieve the nearly zero-energy building (nZEB / sNES) standard, improve indoor comfort, reduce operational energy demand and CO₂ emissions, and modernize outdated building systems in line with Eco fund's requirements.

Trigger for Renovation

The renovation was primarily triggered by the need to replace the aging building envelope and heating system, which caused high energy consumption and poor indoor comfort. The availability of Eco fund's financial incentives further encouraged the deep renovation.

Specific Requirements, Challenges and Barriers

The main challenges included ensuring compliance with the Eco fund's sNES criteria, maintaining architectural integrity of the existing structure, and coordinating works within a semi-detached building where only one dwelling unit was renovated. Limited space for technical installations also required careful design of ventilation and HP systems.

Implementation and Stakeholders

The renovation was implemented between 2021 and 2023 by a private homeowner with the support of specialized contractors for insulation, HVAC, and PV system installation. Energy consulting services ensured compliance with Eco fund's documentation and performance verification. Key stakeholders included the building owner, energy consultant, design engineer, and installation contractors.

10.2 Financing

The comprehensive energy renovation was financed through a combination of private funds, a soft loan from Eco fund, and a non-repayable grant within the national nearly zero-energy building (nZEB / sNES) support scheme.

The total investment in energy-related measures amounted to approx. €86,000. Of this, €28,500 was obtained as a grant from Eco fund, while roughly 50 % of the remaining cost was financed through an Eco fund's low-interest loan with a fixed interest rate of 1.3 %. The rest was covered by the homeowner's own capital.

The investment covered the full thermal envelope insulation, replacement of all windows and doors, installation of a central mechanical ventilation system with heat recovery, an air-to-water HP for space heating and domestic hot-water preparation, and an 11kW rooftop PV system operating under the annual net-metering scheme.

Prior to renovation, the dwelling was heated by a fuel-oil boiler, with a specific heating demand of approx. 215 kWh/m²/a, corresponding to around 5,000 litres of heating oil annually (approx. €6,000/a). After renovation, the heat demand dropped to 22 kWh/m²/a, and the HP covers both heating and hot-water needs with an average seasonal performance factor (COP) of approx. 3.2. Electricity consumption for heating and DHW is fully balanced through the photovoltaic system, resulting in only fixed grid costs of about €10 per month.

Considering the net investment after grant (€57,500) and the annual savings of approx. €5,900, the simple payback period is estimated at around 9.8 years.

The financing model, combining a low-interest loan and grant support, allowed for a deep renovation with a manageable repayment burden and a sustainable long-term return on investment.

Key stakeholders included the homeowner (investor), responsible for financial management and implementation; an energy consultant, who prepared the technical documentation and grant application; and Eco fund, providing both the grant and the favourable loan, as well as post-renovation verification of energy performance.

10.3 Sustainability Performance and KPIs

The operational emissions after renovation are close to zero due to full electricity compensation through annual net metering of the 11 kW PV system. Only negligible residual emissions remain, associated with grid losses and auxiliary power demand.

The following section provides an overview of the KPIs used to measure the renovation progress of the case study building. The indicators may rely on different approaches to value calculation, which are detailed in the last column.

Financial KPIs		
Simple Payback Period	9.8 years	based on energy savings vs. pre-renovation oil heating, after grant

Energy KPIs		
Energy savings per building	$Q_{H,nd,an} = 193 \text{ kWh/m}^2$ (90%) $E_{tot,del,an} = 45.3 \text{ MWh/a}$ (100%)	$Q_{H,nd,an}$ (before renovation) = 215 kWh/(m ² a) $Q_{H,nd,an}$ (after renovation) = 22 kWh/(m ² a) $E_{tot,del,an}$ (before renovation) = 248 kWh/(m ² a) $E_{tot,del,an}$ (after renovation) = 0 kWh/(m ² a)
Amount of primary energy saved	52 MWh/a (100%)	$E_{Ptot,an}$ (before renovation) = 52 MWh/a $E_{Ptot,an}$ (after renovation) = 0 MWh/a
Share of energy from RES	100 %	$E_{Pren,an}/E_{Ptot,an}$
Energy from RES	11 kW installed	12 MWh produced
Environmental KPIs		
Annual operational GHG reduction	13 tCO ₂ /a (100%)	calculated from 5,000 L heating oil × 2.68 kg CO ₂ /L, reduced to near-zero after renovation

10.4 Lessons Learned and Key Recommendations

The deep renovation of the semi-detached building in Ljubljana provided valuable insights into the technical, financial, and organizational aspects of achieving the nearly zero-energy building (sNES/nZEB) standard in existing residential structures.

Lessons Learned

- ▶ A **comprehensive and well-coordinated design phase** is essential for integrating envelope, ventilation, HP, and PV systems efficiently. Early energy modelling and on-site assessment significantly reduce later technical issues.
- ▶ The **combination of grant and low-interest financing** offered by Eco fund proved critical to make deep renovation financially viable for private homeowners.
- ▶ Annual **net-metering** effectively balances renewable generation and electricity consumption, allowing for near-zero operational energy costs and emissions.
- ▶ Implementing a full sNES renovation in a **semi-detached house** required careful coordination with the neighbouring unit to avoid structural and aesthetic conflicts.
- ▶ The actual execution confirmed that **air-tightness and ventilation commissioning** play a decisive role in achieving projected performance and indoor comfort.

Key Recommendations

- ▶ Promote **integrated renovation packages** that include both envelope and system upgrades to ensure long-term performance.
- ▶ Strengthen **technical support programs** for homeowners, especially regarding design coordination and grant application.
- ▶ Encourage the use of **renewable on-site generation with net-metering** in all deep renovations, as it ensures operational carbon neutrality.

- ▶ Develop clear **communication and coordination guidelines** for semi-detached or multi-unit buildings undergoing partial renovations.
- ▶ Include **post-renovation monitoring and user training** as standard practice to maintain EE and system reliability over time.

11 | Conclusions

11.1 Summary of Key Findings

The analysis of 9 case studies across five European countries demonstrates that integrated renovation approaches—combining EE, seismic strengthening, and the integration of RES—are both technically feasible and socially beneficial, though often dependent on targeted financial support.

Across the sample, energy demand was reduced by 40–75%, with primary energy savings averaging 50%. GHG emissions decreased by 45–90%, confirming that holistic renovation can significantly enhance decarbonisation efforts in the building sector.

Case number	1	2	3	4	5	6	7	8	9
County	IT	GR	GR	BE	AUT	AUT	SI	SI	SI
Building type	Public building - Educational building	Residential building - Single-family house	Non-residential building - Hospital	Residential building - Single-family house	Residential building - Apartment block	Residential building - Single-family house	Public building - Educational building	Public building - Educational and healthcare buildings	Residential building - Semi-detached residential building
Energy savings									
Need					71%	82%	61%	69%	90%
Final		80%			75%	90%	47%	58%	100%
Primary		93%			82%	86%	42%	69%	100%
RES	35%			89%	45%	96%	47%	82%	100%

From a financial perspective, incremental investment costs ranged between €100–600/m², with economic benefit–cost ratios (BCR) exceeding 1.2 in most cases, highlighting strong socio-economic justification even where private financial returns were limited. Projects involving combined financing—mixing grants, low-interest loans, and EnPC—showed the highest replicability potential.

Case studies further illustrate those public buildings, particularly schools and municipal facilities, serve as ideal pilots for demonstrating scalable renovation models due to their high visibility, multi-functional use, and social relevance.

Finally, the findings confirm that integrating seismic and energy retrofitting not only improves safety and comfort but also enhances asset value and resilience, positioning such renovations as strategic long-term investments rather than short-term costs.

The comparative overview of the nine GreenRenoV8 case studies reveals a wide diversity in both the **typology of buildings** and the **scope of implemented renovation measures**, reflecting the heterogeneity of national contexts and policy frameworks.

Energy renovation actions were most frequently focused on **building envelope improvements**, including insulation, window replacement, and upgrades of heating and ventilation systems. In countries with more advanced regulatory frameworks (e.g. Austria, Belgium), measures also extended to **smart controls, hydraulic balancing, and integration of energy monitoring systems**, indicating a shift toward performance-based renovation approaches.

In terms of **renewable energy integration**, **PV systems** emerged as the most common technology, often combined with **heat pumps** and, in some cases, **energy storage** (e.g. CS2–GR, CS5–AUT). The extent of renewable integration, however, varied significantly: while some projects achieved near-complete substitution of fossil-based systems, others—particularly educational and public buildings—focused on **preparatory provisions** for future PV installation rather than immediate deployment.

From the **seismic renovation perspective**, interventions ranged from comprehensive structural strengthening (CS1–IT, CS3–GR, CS9–SI) to partial reinforcement or qualitative improvements (CS7–SI). The Italian and Greek projects implemented **modern composite and CAM systems**, whereas Slovenian examples relied more on **conventional reinforced concrete and FRG-based techniques**, reflecting differences in design practice and available expertise.

Renovation costs also varied widely, from below **€700/m²** for standard envelope upgrades to over **€1,800/m²** for combined energy and seismic renovations in public buildings. Funding structures mirrored national conditions: **Italy and Slovenia** relied heavily on **grant-based schemes**, while **Austria and Belgium** applied **mixed financing models**, combining own funds, loans, and public incentives.

Overall, the comparison illustrates that **integrated renovation approaches are feasible across all building typologies**, but their implementation depends strongly on local regulatory, technical, and financial environments. Countries with dedicated funding mechanisms for seismic retrofitting achieve deeper, more balanced outcomes, while others still prioritise energy efficiency as the primary renovation driver.

11.2 Lessons Learned

The comparative analysis of the case studies demonstrates that **successful integrated renovations** depend on early coordination between **technical, financial, and administrative stakeholders**. Projects in which energy, seismic, and architectural interventions were co-designed within a single planning framework achieved smoother implementation, better cost control, and higher overall performance.

A clear lesson emerging across countries is the importance of **multi-source financing models**. The most effective projects combined **public grants**—which often covered between 60% and 85% of investment costs—with **private loans or own funds**, ensuring both affordability and stakeholder commitment. National differences were evident: **Italy and Slovenia** relied predominantly on grant-based schemes, whereas **Austria and Belgium** implemented mixed approaches with stronger participation of **ESCOs** and municipal actors. These models fostered trust, reduced financial risk, and improved project scalability.

On the technical side, the **integration of renewable energy systems**, primarily PV installations and heat pumps, proved highly replicable across building typologies. In contrast, **seismic retrofitting** exhibited greater variability—ranging from advanced composite strengthening in Italy and Greece to more conventional reinforcement techniques in Slovenia—reflecting disparities in design standards, expertise, and regulatory enforcement. This highlights the need for **consistent guidelines and funding mechanisms** that incentivize balanced investments in both energy and seismic domains.

Another key finding concerns **data transparency and standardization**. In several countries, fragmented or incomplete EPC databases and limited availability of investment documentation constrained the ability to compare performance indicators. Improving access to reliable data is therefore essential for **evidence-based policy-making** and investor confidence.

Finally, **public-sector leadership**—particularly through municipal and educational buildings—was shown to accelerate market uptake by serving as demonstrative examples of good practice. These projects illustrate that when supported by strong governance and blended financing, **integrated renovations can deliver both climate resilience and structural safety**, turning public investments into long-term social and environmental value.

11.3 Barriers and Challenges

Despite the positive outcomes observed in the case studies, several **systemic and operational barriers** continue to hinder the large-scale deployment of integrated renovation models across Europe.

The **limited availability and transparency of technical and financial data** remain among the most critical obstacles. Detailed information on investment costs, funding composition, and post-renovation performance is often missing—particularly for privately financed or small-scale projects. This lack of accessible data prevents accurate benchmarking, replication, and the development of risk assessment models required by investors and financial institutions.

Regulatory and administrative fragmentation also poses significant challenges. In most Member States, **energy and seismic retrofitting are governed by separate legal frameworks, funding programmes, and approval procedures**, which rarely align in timing or eligibility criteria. This institutional divide results in inefficiencies, procedural delays, and missed opportunities for truly integrated design. The Slovenian experience illustrates that while energy renovation processes are well regulated and systematically implemented, **seismic design and verification remain inconsistently enforced**, often allowing simplified assessments that fall short of Eurocode 8 standards.

On the **financial side**, high upfront investment costs and the **absence of dedicated financing instruments for combined energy–seismic interventions** limit private-sector participation. Public grants tend to prioritise energy efficiency, leaving seismic strengthening underfunded despite its critical role in resilience.

From a **technical perspective**, integrating multiple renovation dimensions—energy efficiency, seismic retrofitting, and renewable energy—substantially increases design complexity. This requires **interdisciplinary expertise** that is not yet broadly available in most markets, especially within smaller engineering firms or local administrations.

Finally, **institutional and market capacity** remain uneven across the participating countries. Limited awareness among decision-makers and a shortage of trained professionals capable of managing holistic projects continue to impede progress. Strengthening capacity-building efforts, enhancing regulatory coherence, and developing tailored financial mechanisms are therefore essential to bridge the gap between energy policy ambitions and practical implementation of integrated, resilient renovations.

11.4 Success Factors

The most successful case studies share several common enabling factors. Early integration of technical, financial, and administrative planning proved decisive in minimizing project complexity and ensuring coherence between energy and seismic interventions. Access to blended financing—combining EU or national grants with soft loans, tax incentives, or EnPC—was a critical success factor, allowing municipalities and private owners to overcome high upfront costs.

Strong institutional leadership and project governance, particularly from local authorities and public agencies, fostered stakeholder alignment and long-term commitment. The involvement of experienced design teams and construction firms with cross-disciplinary expertise ensured quality and reduced implementation risks.

Finally, projects that included renewable energy integration, user engagement, and continuous performance monitoring demonstrated higher replicability and social acceptance. These elements collectively confirm that technical innovation must be supported by robust governance and financing models to achieve sustainable, large-scale renovation outcomes.

11.5 Policy Implications

The case studies underline the urgent need for integrated policy frameworks that address energy efficiency, seismic safety, and sustainability as interlinked objectives rather than parallel priorities. Across Europe, regulatory and financial instruments supporting energy renovation are well developed, while seismic strengthening remains under-regulated and insufficiently financed. This fragmentation leads to missed opportunities, higher cumulative costs, and in some cases, technically inconsistent or unsafe outcomes.

The Slovenian experience clearly illustrates this gap. While energy renovation projects—particularly in public buildings—are strongly supported through grants and national programmes, the accompanying seismic assessments are often partial or simplified. Current legislation allows “adequate” rather than comprehensive verification against Eurocode 8 (EC8) standards, meaning that structural safety may not be fully ensured even after substantial investment. This highlights a systemic imbalance between decarbonisation and physical resilience objectives.

At the macro level, this imbalance reflects a broader European challenge: the drive to meet climate targets and reduce building-sector emissions has created strong political and financial momentum for energy renovation, but similar ambition is lacking for seismic resilience. In seismically active regions such as Slovenia, Italy, and Greece, these two processes must evolve in parallel, not sequentially. Otherwise, the continent risks achieving climate resilience without ensuring structural safety.

To address this, policy frameworks should:

- ▶ Integrate seismic assessment and strengthening into all major renovation programmes, ensuring compliance with EC8 principles as a precondition for public funding.
- ▶ Introduce combined financing schemes that support both energy and structural interventions within a single investment cycle.
- ▶ Promote capacity building and interdisciplinary design methodologies for engineers, auditors, and local authorities.
- ▶ Establish data transparency and KPI frameworks covering energy, seismic, and environmental performance.
- ▶ Use public buildings as demonstration sites, showcasing how integrated renovations can enhance both sustainability and safety.

Ultimately, achieving a resilient, decarbonised building stock requires that every euro invested in energy efficiency also contributes to structural integrity. Only by aligning climate resilience with physical resilience can Europe ensure that its renovation wave delivers long-term value and safety for its citizens.

11.6 Outlook

The findings from Deliverable 4.3 will directly inform the next stages of the GreenRenoV8 project, particularly the development of the GreenRenoV8 Toolbox (D4.5) and the accompanying Guidelines for Integrated Renovation Models (D5.1). The empirical insights gathered from the case studies—covering technical, financial, and governance dimensions—will serve as the foundation for designing replicable financing schemes and risk-assessment tools that reflect the realities of implementation across Europe.

In practical terms, the data and lessons learned will feed into the creation of model-based scenarios, enabling stakeholders to evaluate the financial viability, risk distribution, and long-term impacts of integrated renovation projects. The Toolbox will also translate complex KPIs into accessible decision-support instruments for policymakers, financial institutions, and local authorities.

Looking forward, GreenRenoV8 aims to move beyond demonstration and toward mainstream adoption of integrated renovation practices. This involves extending the network of pilot regions, refining the policy recommendations based on stakeholder feedback, and promoting collaboration between the energy, construction, and finance sectors.

Ultimately, the project envisions a European renovation ecosystem where energy efficiency, seismic resilience, and sustainability are addressed simultaneously within coherent regulatory and financial frameworks. The outputs of D4.3 provide a crucial empirical bridge between analysis and action—helping to ensure that future renovation policies and investments are both climate-aligned and structurally resilient.

Case Study Comparative Table

Building overview		CS1 - IT - Public building - Educational building	CS2 - GR - Residential building - Single-family house	CS3 - GR - Non-residential building – Hospital	CS4 - BE - Residential building – Single-family house	CS5 - AUT - Residential building – Apartment block	CS6 - AUT - Residential building – Single-family house	CS7 - SI - Public building – Educational building	CS8 - SI - Public building – Educational and healthcare buildings	CS9 - SI - Residential building – Semi-detached residential building
Building type		Public building - Educational building	Residential building - Single-family house	Non-residential building – Hospital	Residential building – Single-family house	Residential building – Apartment block	Residential building – Single-family house	Public building – Educational building	Public building – Educational and healthcare buildings	Residential building – Semi-detached residential building
Implemented energy renovation measures	Energy		wall and roof insulation	replacement of masonry infills with insulated walls	envelope improvement, windows and doors	building envelope insulation, window and door upgrades, ventilation improvements, hydraulic balancing and smart control	thermal envelope upgrades, window replacement	façade and roof insulation, new high-efficiency windows/doors, upgraded heating and ventilation, full LED lighting, and central energy monitoring.	façade and roof insulation, new HVAC and mechanical ventilation with heat recovery, full LED lightning, introduction of BMS	comprehensive thermal insulation of all envelope elements, replacement of windows and doors, installation of central ventilation with heat recovery
	RES	PV system installation	PV system, batteries, heat pump		new mechanical ventilation system and heat pump	PV system, heating system replacement, hot water storage system	PV system, heating system replacement	technical provisions for future PV system installation		PV system, transition to an air-to-water heat pump for heating and domestic hot water

Building overview		CS1 - IT - Public building - Educational building	CS2 - GR - Residential building - Single-family house	CS3 - GR - Non-residential building – Hospital	CS4 - BE - Residential building – Single-family house	CS5 - AUT - Residential building – Apartment block	CS6 - AUT - Residential building – Single-family house	CS7 - SI - Public building – Educational building	CS8 - SI - Public building – Educational and healthcare buildings	CS9 - SI - Residential building – Semi-detached residential building
	Seismic	seismic strengthening using CAM system		structural strengthening with CFRP composites				reinforced concrete walls, steel frames, and plaster strengthening to improve structural stability and seismic safety.	structural reinforcement using new RC shear walls and frames, FRG coatings, foundation strengthening, structural connection improvements between wings	
Floor area renovated (m2)		1.100	108	568	150	720	120	4.678	7.039	186
Renovation cost (€/m²)	Energy	0.00 €	ND	ND	0.00 €	0.00 €	1.676.10 €	267.85 €	488.46 €	478.49 €
	RES	135.14 €	ND	ND	0.00 €	0.00 €	171.80 €	0.00 €	0.00 €	
	Seismic	572.73 €	ND	ND	0.00 €	0.00 €	0.00 €	138.95 €	150.43 €	
	Total	707.86 €	ND	ND	1.266.67 €	763.89 €	1.847.90 €	769.56 €	698.68 €	
Funding structure (in %)	Own funds	19%	ND	100%	32%	39%		65%	15%	18%
	Grant	81%	ND			61%	49%	14%	85%	32%
	Regular Loan				68%					
	Renovation Loan						51%			50%
	EnPC							21%		

References

CS1 - IT - Public building - educational building

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