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EASI ZERo

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Deliverable

ENVELOPE MATERIAL SYSTEM WITH LOW IMPACT FOR ZERO ENERGY RENOVATION AND CONSTRUCTION

Deliverable ID	**D6.2**
Deliverable name	**"Use case buildings energy modelling & simulation"**
Deliverable description	This deliverable will show two parts (task 6.3): - modelling of buildings based on existing BIM data with comparison on real performance; the energy consumption model will define a baseline performance for operational energy consumption and GHG emissions. - the simulation of a complete refurbishment will be described using materials and components from the project.

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Glossary

BEM: Building Energy Model

CO2: Carbon Dioxide

CVRMSE: Coefficient of Variation pf the Root Mean Square Error

kWfFE: KWh of final energy

EZ0: Easi Zero

IESVE: Integrated Environmental Solutions Virtual Environment

KPI: Key Performance Indicator

NMBE: Normalized Mean Bias Error

SRC: Standardized Regression Coefficients

1. Executive summary

1.1 *Description of the Deliverable content and objectives*

The Deliverable 6.2 presents the outcomes obtained within Task 6.2 and Task 6.3 for the three use cases investigated in the EASI ZERo project. The report includes descriptions of the baseline energy modelling developed for each use-case building, the results of the sensitivity analyses carried out for use case 1 and use case 2, and the calibration process performed for u3 based on monitored data. Then, the deliverable assesses renovation scenarios integrating EZ0 panel solutions and evaluates their impact on the buildings' energy performance. Finally, the report provides an analysis of the selected KPIs to compare baseline and renovated scenarios and to quantify the overall benefits of the proposed refurbishment strategies.

1.2 *Deviation from objectives, corrective action*

Initially, the second demonstration site of the EASI ZERo project was planned in Gennevilliers, France. However, the site owner was no longer willing to cooperate, grant access to the building, or allow monitoring activities to proceed. As a result, the site was abandoned, and a new demonstration building had to be identified to ensure the continuity of the project activities.
Subsequently, ELITHIS underwent a judicial reorganisation and was later acquired by a new company OTEIS, which caused additional delays in the implementation of Task 6.2 and postponed the launch of the monitoring campaign.
To limit the impact of these delays on the overall project timeline, the monitoring strategy for use Case 2 was adapted to a lighter, more flexible approach based on short-term measurement campaigns and the use of existing data. In addition, mitigation actions and complementary investigations were planned to complete the required dataset.
Furthermore, the monitoring plan for use Case 1 was cancelled due to ongoing renovation works in the building. As an alternative approach, a sensitivity analysis methodology was adopted to evaluate the reliability of the energy modelling for both use cases.

1.3 *Technical progress*

The three use Cases cover different building typologies, uses, and climatic contexts across Europe: an office building in Würzburg, Germany; a residential building in Saint-Gratien, France; and a building located in Trondheim, Norway. Together, they provide representative case studies for assessing building energy modelling, renovation strategies, BIPV integration, and energy performance improvements under diverse operational and environmental conditions.

1.4 *Impact of the results*

The results obtained from the three use cases demonstrated the strong potential of the EASI ZERo renovation solutions to improve building energy performance and reduce operational carbon emissions across different European climatic conditions.

For use Case 1, the renovation scenarios reduced the final energy consumption from 131 to 34 kWh/m²/year and CO_2 emissions from 15 to 4.5 kg.CO_2/m²/year, achieving up to 74% energy savings. **For use Case 2,** the integration of envelope insulation, heat pumps, and photovoltaic systems reduced the total energy consumption from 125 to 51 kWh/m²/year and CO_2 emissions from 20.4 to 3.9 kg.CO_2/m²/year, corresponding to approximately 60% energy savings. Finally, **for use Case 3**, the calibrated model showed that the renovation measures reduced the heating demand to 37 kWh/m²/year and CO_2 emissions from 1.1 to 0.6 kg.CO_2/m²/year, while the integration of BIPV systems lowered the net thermal energy demand to approximately 13 kWh/m²/year.

1.5 *Dissemination activities carried out, planned*

Use cases have been used in the EASI ZERo online workshop #3 to illustrate the EASI ZERo products potential.

2. Use case n°1: Würzburg, Germany

2.1 *Introduction*

As described in Deliverable D6.1, use case 1 concerns an office building located in Würzburg, Germany, currently undergoing renovation works. Due to these ongoing interventions, continuous monitoring activities and the collection of reliable operational data could not be carried out as initially planned, making a conventional calibration process based on measured data infeasible. In addition, several building parameters remained uncertain due to the limited of detailed information on the building's actual operation. To address these limitations, an alternative methodology based on building energy modeling and parametric sensitivity analysis was implemented. A BEM was developed using IES-VE software to represent the thermal and energy behavior of the building using available design data, standard assumptions, and typical operational profiles. A sensitivity analysis using the Standardized Regression Coefficients (SRC) method was then performed to identify the most influential parameters affecting heating demand and CO_2 emissions and to evaluate the robustness of the simulation results under uncertain conditions. The developed model was finally used as a reference framework to assess the impact of EZ0 renovation solutions and to evaluate the energy, environmental, and operational performance of the proposed renovation scenarios through the project KPIs.

The selection of EZ0 materials is based on a multicriteria analysis aimed at assessing their suitability for integration into the existing building. Each material was evaluated according to its potential applications both interior and exterior and its compatibility with the building's functions (structure, envelope), while considering technical constraints. Site-specific conditions were also considered, including restrictions on interventions to external façades and the building's heritage status, which may limit certain types of modifications. This approach enabled the identification of EZ0 materials that are compatible with the project context and the development of coherent, technically feasible intervention scenarios that preserve the building's performance and structural integrity, while remaining aligned with real-world renovation practices.

2.2 *Case Study Description*

The case study building, as illustrated in Figure 1, is located in Würzburg, Germany, and was constructed in 1903. It is currently used as an office building and consists of a ground floor and three upper storeys, plus a basement level, with a total area of 3,780 m². The building envelope is characterised by external walls made of solid clay bricks, with a thickness ranging from 30 to 40 cm and no additional thermal insulation. Regarding the glazed elements, two types of windows are identified: original wooden windows, representative of the initial construction period, and PVC windows on the second-floor south façade, offering improved thermal performance.

The third-floor level (attic floor) is insulated, although the properties of this insulation remain unknown. This heterogeneity is considered in the modelling approach.
The building is connected to the district heating network operated by the Würzburger Versorgungs- und Verkehrs-GmbH (WVV). The system delivers hot water at a temperature regime of 70/50°C. Space heating is provided by flat panel radiators distributed throughout the building, while domestic hot water (DHW) is produced via heat exchangers connected to the same district heating network.

The 3D geometry was developed based on the architect's DWG drawings. The modelling approach aims to represent the project as accurately as possible while introducing a level of simplification suitable for energy simulation purposes.

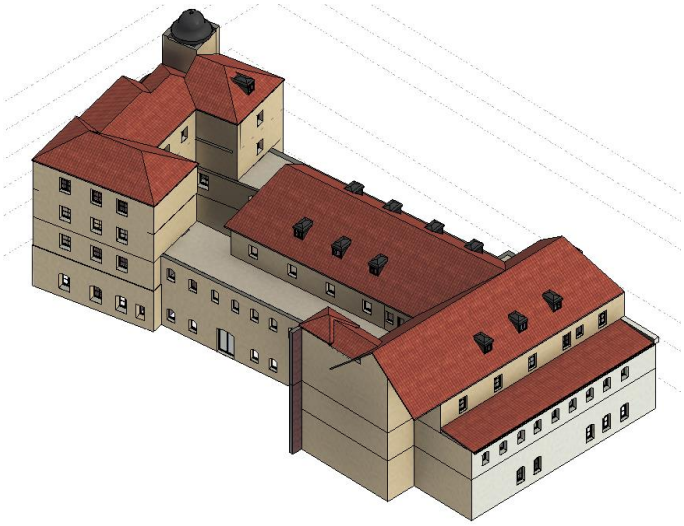


Figure 1:Digital model of the Demo 1 office building developed in Revit

The model has 56 thermal zones, reflecting the internal organization and functional use of the office building. Thermal zoning was established to capture variations in occupancy, internal gains, and usage patterns throughout the building. Typically, spaces with similar thermal behavior such as open-plan offices, meeting rooms, circulation areas, and service spaces are grouped into distinct zones.
The main geometric characteristics used for the energy modelling are summarized in Table 2.

Parameter	Value
Total building volume	12,267 m^3
Total floor area	3,780 m^2
External wall area	1,951 m^2
Total window area	235 m^2
Building height	14.4 m

Number of windows	196

Table 1 : Main geometric characteristics of the demo 1 building

The weather data used in the model were generated from historical data provided by Meteonorm and collected at the Würzburg weather station (49.7949 °N 9.9316 °E).
Internal heat gains are modelled using daily schedules for occupancy, lighting, and equipment use (e.g., computers and office appliances), consistent with typical office building operation. Occupant-related heat gains are estimated from metabolic rates associated with office activities, in accordance with (ISO, 2005), and corresponding sensible heat gains per person are derived from (ASHRAE, 2014). Lighting and equipment power densities (W/m²), as well as occupancy densities, are based on established references such as (Fundamentals, 2021), (EN16798-1) and (CIBSE), ensuring consistency with widely accepted values in building energy simulation.

2.3 *Representative Baseline Model*

2.3.1 Baseline model input dataset

To evaluate the performance and applicability of different scenarios, a representative energy model was developed. Due to the lack of reliable monitoring data, the model could not be conventionally calibrated against measured energy consumption. Therefore average values derived from the possible ranges of uncertain input parameters were used to establish a consistent and representative baseline case. The sensitivity analysis was not used to tune the model, but rather to assess the influence of key uncertain parameters on the building's energy performance. From this reference state, additional scenarios were then defined and simulated, allowing the evaluation of the impact of EZ0 solutions on the building's energy performance.

Building envelope assumptions

Designation	Contact	Type	Resistance (m²·K/W)	U (W/(m²·K))
Exterior walls	Exterior	Solid clay bricks	0.56	1.35
Roof	Exterior	Concrete	0.78	1.05
Floor	Basement	Concrete	0.32	2
Q4Pa (m³/h)		Average		
Leakage level (ACH)		1.5		

Table 2 : Thermal and airtightness characteristics of the existing building envelope

Windows performance

Original wooden windows	
Frame type	Wood
Glazing type	Single glazing
Uw (W/(m².K))	3.5
U frame (W/(m².K))	4.58

g-value (Solar energy transmittance)	0.71

Table 3 : Thermal performance characteristics of the existing windows

Operational assumptions

Traitement	Heating setpoint temperature	Occupation	
	Chauffage	**Heat gain per person**	**Scénario de fonctionnement**
Heating	21°C	125 W (sensible and latent heat)	08:00–18:00, five days per week, with annual shutdown periods of two weeks in August and one week at year-end

Table 4 : Operational assumptions and occupancy schedules used in the energy model

Heating and DHW The building is supplied by the district heating network operated by Würzburger Versorgungs- und Verkehrs-GmbH (WVV). Heat is primarily generated by a gas-fired combined heat and power (CHP) plant (Heizkraftwerk Würzburg), which was converted from coal to natural gas in 2003. The district heating network operates with typical supply and returns temperatures of approximately 90°C and 50°C, respectively.

For domestic hot water (DHW), a supply temperature of 60°C is maintained to ensure both user comfort and sanitary safety, particularly in relation to Legionella prevention. The corresponding return temperature is estimated to range between 30°C and 40°C after heat exchange. the overall heat production efficiency is assumed to be 0.90.

Ventilation and air exchange Natural ventilation was modelled in IESVE using MacroFlo opening types assigned to external windows. Each opening was defined according to its exposure, opening category, and effective openable area. Background infiltration was represented separately using a fixed air change rate of 0.6 ACH. Window operation was controlled through a temperature-based modulating profile, to realistically represent occupant behaviour in office buildings. Windows remain closed at low indoor temperatures and begin to open progressively as indoor temperature exceeds a defined comfort threshold (around 22–24°C), reaching higher opening ratios above 26°C and approaching full opening near 28°C under favourable outdoor conditions. During colder periods, window opening is kept to a minimum (below 3%) and occurs only intermittently to limit heat losses while ensuring basic air renewal, consistent with adaptive comfort approaches and natural ventilation modelling practices ((EN16798-1) and (CIBSE))

Lighting the adopted lighting power density values are derived from typical benchmarks for office buildings, as defined in (EN15193)**.**

Zones	Power density (W/m²)
offices, meeting rooms	10

Circulations areas, sanitary	8
Storage Room	5

Table 5 : Lighting power density assumptions used for the different building zones

Office equipment

Office equipment power densities are defined to represent the internal gains generated by computers and various IT devices. This assumption is also considered in the assessment of energy consumption.

Zone	Load type	Power density (W/m²)
Offices	Office equipment	15

Table 6 : Office equipment power density assumptions

2.4 *Use case 1 - Baseline results*

The analysis was initiated with the building heat balance to verify the consistency of the model and to identify the most significant sources of heat losses at the building scale. The results show that external walls account for the largest share of heat losses (27%), followed by Ground floor (26%) and ventilation/infiltration (22%). Roof losses represent 16%, while external windows contribute 10%, with doors remaining negligible. Overall, total heat losses are estimated at approximately 505 MWh.

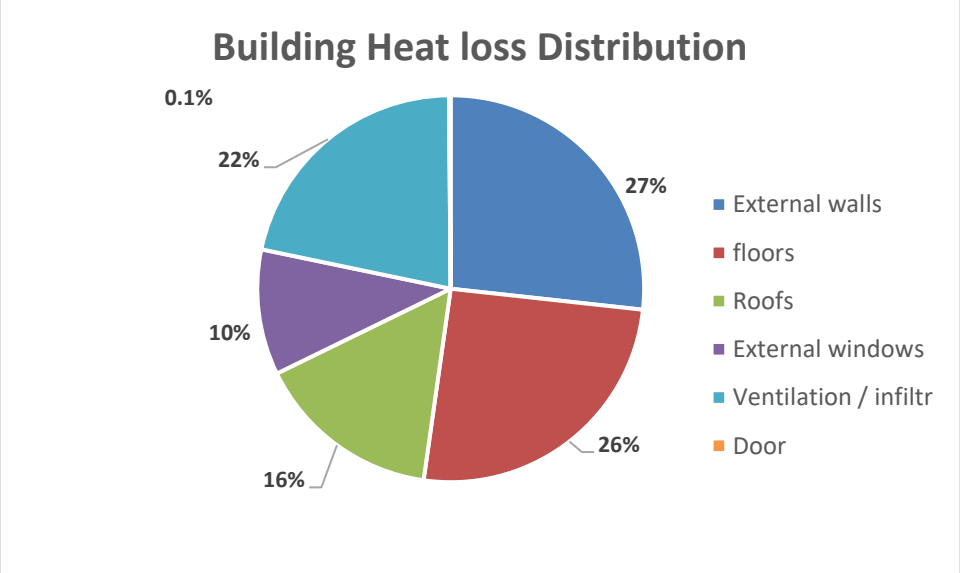


Figure 2 : Building Heat loss Distribution

The energy consumption results are presented in the table below.

End use category	Final Energy Consumption [kWh]

		District Heating Consumption	Electricity
Heating		397,581	
Cooling		-	-
Domestic hot water		5,722	
Lighting			84,105
Auxiliaries			7,909
Total	[kWh]	495,317	
	[kWh/year/m²]	131	
End use category		**CO_2 emissions [kg.CO_2]**	
		District Heating Consumption	Electricity
Heating		26,717	
Cooling		-	-
Domestic hot water		384	
Lighting			28,848
Auxiliaries			2,713
Total	[kgCO_2]	58,662	
	[kgCO_2/year/m²]	15.5	

Table 7 : Baseline of use case 1- Energy Consumption and CO_2 emissions

The results indicate that heating demand represents the dominant share of the building's energy consumption, accounting for approximately 80–90% of the total final energy use, primarily supplied by the district heating network. Domestic hot water is also covered by the same system, while electricity consumption is mainly associated with lighting, plug loads, and auxiliary systems. It should be noted that auxiliary energy only includes the substation components (e.g., circulation pumps and heat exchangers), as no mechanical ventilation system is considered in the model.

For the carbon assessment, specific emission factors were applied to each energy carrier. District heating was assigned a coefficient of 0.0672 kg.CO_2/kWh, reflecting the relatively low carbon intensity of the Würzburg network, based on a mix of gas-fired cogeneration, waste incineration, and heat recovery (Effizienzhaus) Electricity consumption was evaluated using a factor of 0.343 kgCO_2/kWh, representative of the German electricity mix (Agency). These assumptions highlight the significant advantage of district heating in reducing CO_2 emissions compared to conventional systems, while electricity remains the main contributor to the building's indirect carbon footprint.

2.5 *Renovation Scenario Modelling*

This use case is officially listed in the Bavarian Monument Register (Denkmalliste), classifying it as a protected historical monument (Baudenkmal). Consequently, any demolition or modification affecting the exterior requires prior approval from the local monument protection (Denkmalschutzbehörde). In practice, this significantly restricts possible interventions: external

thermal insulation is generally not permitted, as it would alter the historic façade. Renovation strategies therefore prioritize internal insulation and targeted improvements to the roof, basement, and windows. In this context, the EZ0 project proposes materials and solutions specifically adapted to these constraints, designed for internal or non-visible applications, enabling energy performance improvements while preserving the building's heritage value.

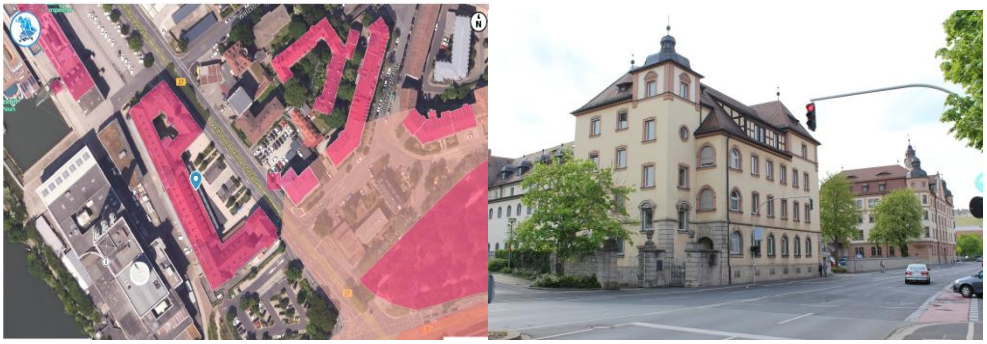


Figure 3 : Location and external view of the use case 1 study building in Würzburg, Germany

Three renovation scenarios were developed to assess different pathways for improving the building's energy performance and moving closer to the targeted objectives. The first scenario focuses on building systems and operational improvements, such as the replacement of outdated lighting systems with more efficient solutions and the optimisation of HVAC-related components, which can provide cost-effective energy savings before considering more expensive envelope interventions. The second scenario addresses building envelope improvements, including insulation measures and window replacement, in order to reduce heating demand and establish a more efficient energy baseline. Finally, the third scenario builds on the previous measures by integrating renewable energy production, through the assessment of photovoltaic panels on the roof and, where feasible, on selected façade areas. The renovation solutions considered in the programme are summarised in the table below.
The renovation solutions presented in the program are summarized in the table below.

Renovation variants	EZ0 Products
V1 – Opaque Envelope	• External Walls insulation: Mycelium-based inside-the-wall thermal insulating panels 50 mm + Wood-fibre insulation panel 50 mm • Attic floor insulation (top floor): sprayable low-density Bio-PUR foam 300 mm • Attic roof (attic slopes) + non-accessible roofs insulation: 220 mm of wood fibre panel • Floor over basement insulation: Wood-fibre insulation panel in wall assembly 220 mm
V2 - Windows	• Window with bio PUR paint Uw =1.1W/m²K

V3 - Lighting	• LED replacement Installed power 3 W/m²
V4 – Photovoltaic System	• Installation of photovoltaic panels on the roofs, and PV tiles on attic roofs: Rooftop photovoltaic system: 13 PV panels with an installed capacity of 6.37 kWp, covering a total area of 28.7 m². Attic roof photovoltaic system: 45 EDILIANS photovoltaic tiles with an installed capacity of 4.5 kWp, covering a total area of 26.54 m².

Table 8 : Use case 1-Renovation Variants and Associated EZO Products

The results of the different renovation scenarios are summarized in the table below.

		Final Energy Consumption [kWh]			
		Baseline	**Scenario 1** (envelope)	**Scenario2** (envelope+ systems)	**Scenario3** (envelope+ systems)
Energy uses		**V0**	**V1+V2**	**V1+V2+V3**	**V1+V2+V3+V4**
Heating	Gas	397,581	82,823	92,574	92,574
DHW	Gas	5,722	5,722	5,722	5,722
Lighting	Elec	84,105	84,105	36,868	36,868
Auxiliary systems	Elec	7,909	7,909	7,909	7,909
PV production					-14,837
Total kWhFE		**495,317**	**180,550**	**143,064**	**128,227**
kWhFE/m²		**131**	**48**	**38**	**34**
Savings			**-64%**	**-71%**	**-74%**

Table 9 : Use case 1-Results of Energy Consumption and Energy Savings for the Baseline and Retrofit Scenarios

The results highlight a very significant improvement in energy performance between the baseline and the different scenarios assessed. The comprehensive building retrofit implemented in Scenario 1 alone leads to a 64% reduction in total energy consumption, decreasing from 131 to 48 kWhFE/m²·yr. This reduction is mainly driven by the enhancement of the building envelope, which substantially lowers heating demand. In Scenario 2, the upgrade of the lighting system through the

replacement of conventional fixtures with LED technology results in a further reduction, reaching 71% savings overall. This improvement is primarily due to the significant decrease in electricity consumption for lighting. However, a slight increase in heating demand is observed, which can be explained by the reduction in internal heat gains, a well-known effect in building energy performance. Finally, Scenario 3 incorporates on-site renewable energy production through the installation of photovoltaic panels on suitable roof areas. This measure further improves the overall performance, achieving a total reduction of 74%, corresponding to 34 kWhFE/m²·yr. The local generation of electricity contributes to lowering the final energy consumption, thereby enhancing the building's overall energy efficiency.

2.6 *Parametric study*

2.6.1 Introduction

As many input parameters in this model are subject to a certain degree of uncertainty mainly due to limited knowledge regarding their exact values, a sensitivity analysis was carried out as an alternative approach. This step represents a crucial part of the modelling process, enabling the generation of more reliable results and valuable insights, while increasing confidence in the model's outcomes. The sensitivity analysis was carried out to assess the influence of uncertain input parameters on the model results and to better understand their impact on the building's energy performance.

2.6.2 Sensitivity analysis for use case 1

A sensitivity analysis was conducted for use case 1 to identify the variables that significantly influence key performance indicators (KPIs), namely energy consumption and CO_2 emissions. For this analysis, ten uncertain parameters were selected within the IESVE model, allowing for a detailed assessment while maintaining a reasonable computational effort. The analysis was carried out for both pre-renovation and post-renovation scenarios. The selected parameters are specific to the studied model and its components, including, for example, the infiltration rates and the thermal transmittance (U-values) of the building envelope. Table 3 presents the set of variables considered for Demo 1.

		Case 1				
Variable name	Unit	Existing case	Refurbishment case	Var. 1	Var. 2	Var. 3
Infiltration rate	ACH	0.6	0.2	Existing: 0.6/0.8 Refurb: 0.1/0.2		
Wall U-value	W/m²K	1.35	0.15	Existing : 1/1.9 Refurb : 0.11/0.18		
Roof U-value	W/m²K	1.05	0.14	Existing : 0.8/1.25 Refurb: 0.12/0.17		

Floor U-value	W/m² K	2.05	0.14	Existing: 1.7/2.5 Refurb: 0.12/0.17
Window U-value		3.5	1.14	Existing: 3/4 1.1 / 1.3
Occupancy Density	m²/p	10	10	8
People sensible gain	W/ m²	60	60	60
Lighting	W/m²	10	3	8/12 3/5

Table 10 : Variables for sensitivity analysis for Demo 1

The sensitivity analysis in this study is carried out using a multiple linear regression model to evaluate the relationships between input variables and building energy performance. This approach allows for the identification and prioritization of the most influential parameters affecting heating demand, energy use, and CO_2 emissions. The analysis relies on the standardized regression coefficient (SRC) to measure the relative contribution of each variable, where higher absolute values indicate stronger effects and the sign reflects the direction of influence. The statistical robustness of the results is assessed through p-values, with a significance threshold set at 0.05. Furthermore, the overall performance of the regression model is evaluated using the adjusted R^2, with values above 0.7 indicating a satisfactory level of explanatory power and values close to 1 demonstrating a high level of model accuracy. SRC values were calculated for the parameters and ranges shown in Table 3 by applying linear regression analysis to the results obtained from a full factorial parametric simulation, comprising 1,024 simulation runs.

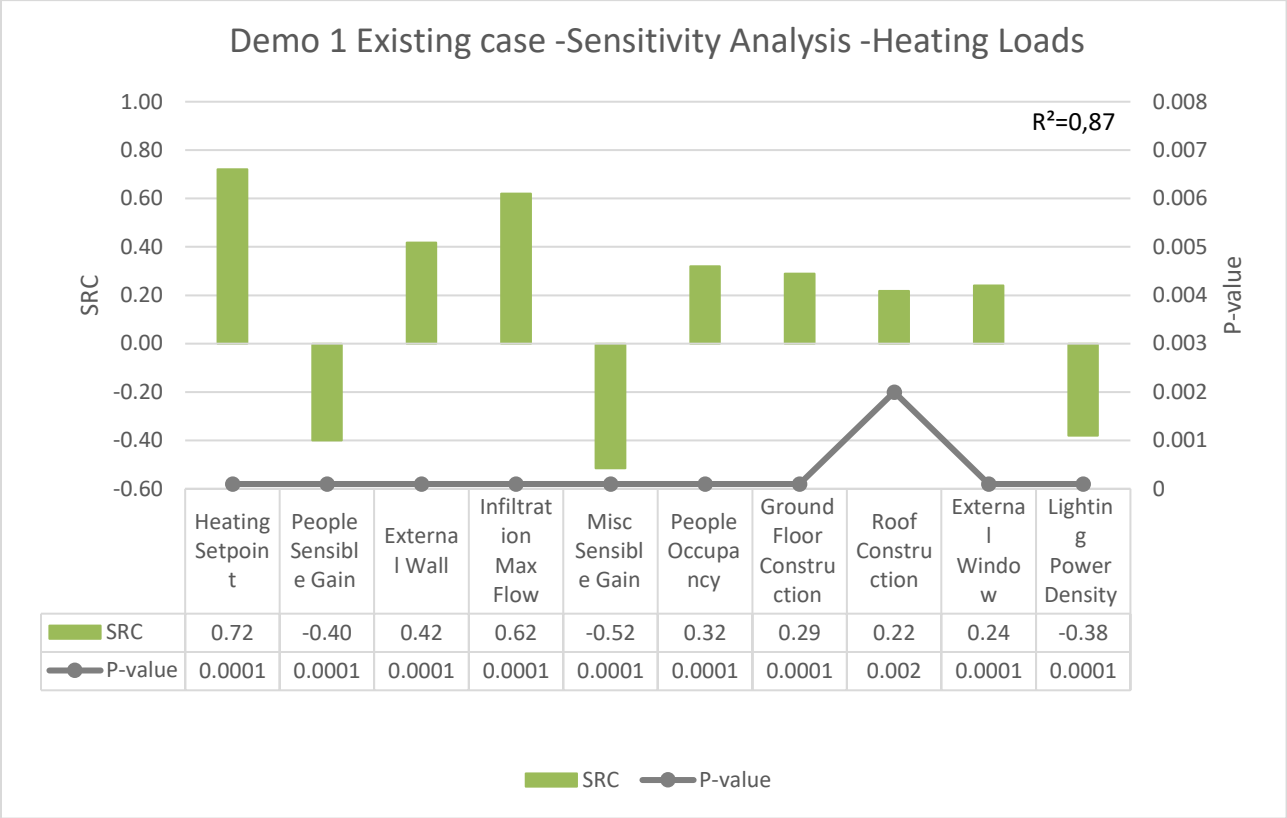


Figure 4 : Sensitivity analysis for heating loads – use case 1 existing case

The sensitivity analysis of the use Case 1 existing case indicates that several parameters strongly influence the building's heating demand. The most influential parameter is the heating setpoint temperature, with the highest SRC value (around 0.72), followed by infiltration (SRC ≈ 0.62) and miscellaneous sensible gains (SRC ≈ −0.52). These three parameters have the strongest impact on the heating behaviour of the building.

A second group of parameters shows a moderate but still significant influence, with SRC values between approximately 0.35 and 0.50. This includes external wall performance (SRC ≈ 0.42), people sensible gains (SRC ≈ −0.40), and lighting power density (SRC ≈ −0.38). These results highlight the importance of both envelope-related parameters and internal heat gains in the heating demand calculation.

Other parameters have a more limited influence, with SRC values below approximately 0.35. This includes occupancy density (SRC ≈ 0.32), ground floor performance (SRC ≈ 0.29), window performance (SRC ≈ 0.24), and roof performance (SRC ≈ 0.22). Overall, the results show that the heating demand is mainly driven by the heating setpoint, infiltration, and internal gains, while envelope performance parameters also contribute to the building's thermal behaviour.

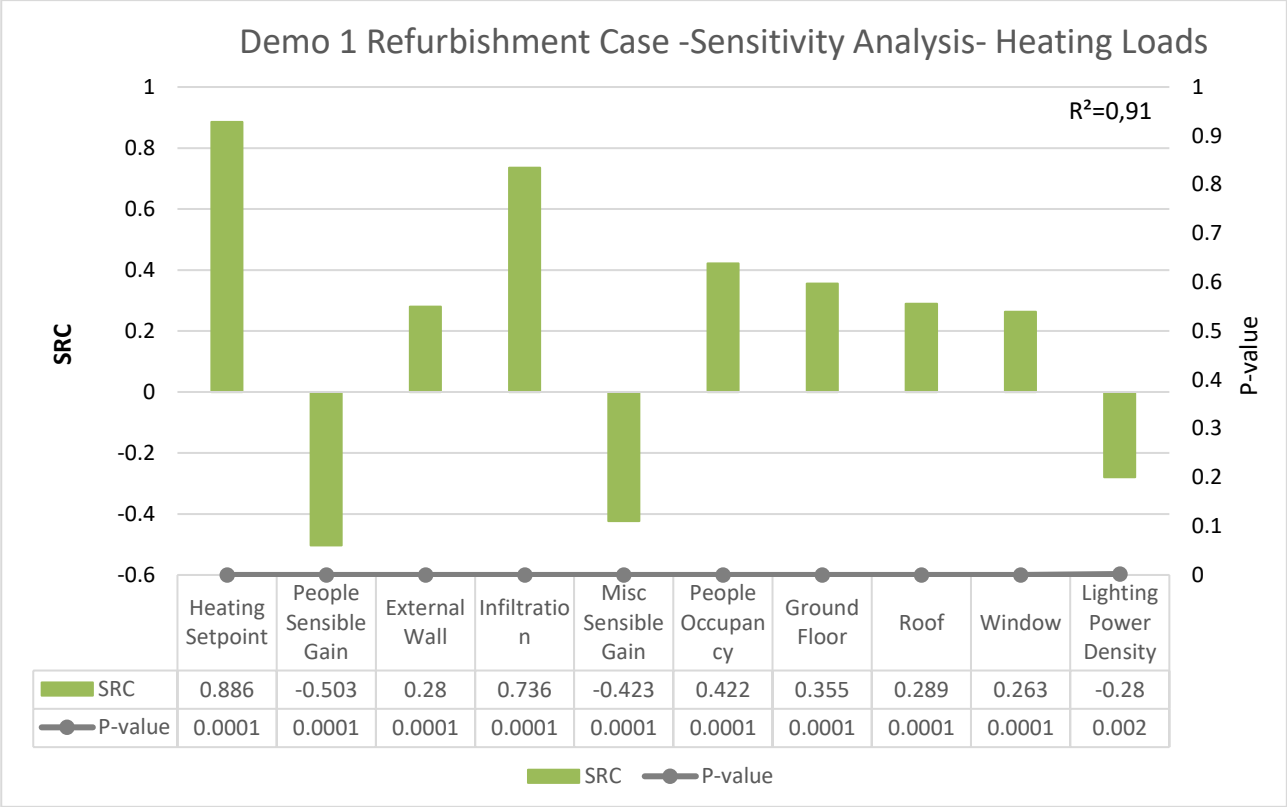


Figure 5 : Use case 1 Refurbishment Case – Sensitivity Analysis – Heating loads

The results of the refurbishment scenario show trends that are broadly consistent with those observed in the existing case. The heating setpoint remains the most impacting factor influencing heating demand, with an SRC of 0.886, confirming its key role in the building's thermal behavior. Infiltration also emerges as a major contributor, with an increased relative importance compared to the initial state. This is expected, as the improvement of the building envelope reduces transmission losses, making air leakage more influential in comparison. The results indicate that after refurbishment, heating demand becomes strongly influenced by operational parameters such as setpoint, airtightness and internal gains.

2.6.3 Results for use case 1

The boxplot results are shown in figure 4, illustrating the heating loads distribution from 1024 simulations performed for the sensitivity analysis.

The results obtained from the parametric simulations provide a comprehensive overview of the variation in final energy consumption and CO_2 emissions between the existing and retrofitted cases. The tables 12, 13 and 14 present the minimum, mean, and maximum values for each end-use, highlighting the impact of the refurbishment measures. Overall, the retrofit leads to a significant reduction in total final energy consumption, decreasing from an average of 183 kWh/m² to 93 kWh/m², corresponding to an average saving of approximately 49%. A similar trend is observed for

heating demand, which shows the most substantial reduction, decreasing from 153 kWh/m² to 76 kWh/m² (≈51% reduction), reflecting its dominant contribution to total energy use.

In terms of CO_2 emissions, a significant reduction is also observed, with total emissions decreasing from 20 to 10 kg.CO_2/m², corresponding to an average saving of approximately 49%. The reduction in emissions is slightly lower than the reduction in energy consumption, which can be explained by the different energy carriers involved. Heating is primarily supplied by gas, while other end-uses such as lighting rely on electricity, each associated with different emission factors.

The results also show a noticeable range between minimum and maximum values for both energy consumption and CO_2 emissions. For instance, total final energy consumption varies from 137 to 223 kWh/m² in the existing case and from 57 to 152 kWh/m² after refurbishment. This variability indicates a strong sensitivity of the system to input parameters. Although the retrofit significantly reduces both the average values and the overall dispersion, a residual variability remains, highlighting the importance of key parameters and their interactions in determining the building's performance.

Overall, these findings confirm the effectiveness of the refurbishment measures while emphasizing the relevance of the sensitivity analysis in capturing the range of possible outcomes and supporting a more robust interpretation of the simulation results.

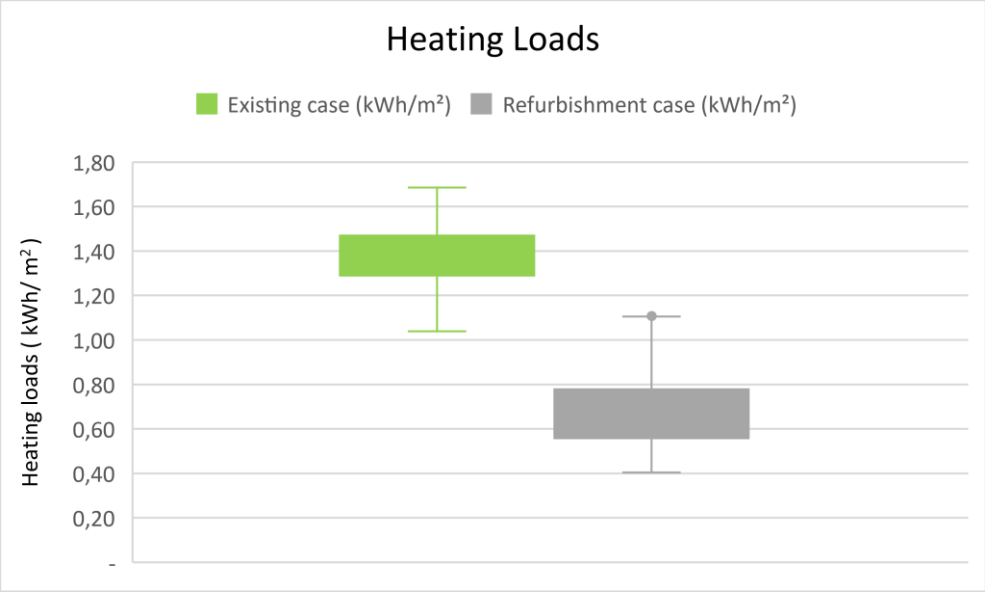


Figure 6 : Distribution of heating loads for the existing and refurbishment cases

Thermal Energy Demand (KWh/m²)									
	Existing			Retrofitted			Savings		
	Mean	Min	Max	Mean	Min	Max	Mean (%)	Min (%)	Max (%)
Heating Loads	137	103	168	68	40	113	51%	63%	33%

Table 11 : Thermal energy demand comparison between the existing and retrofitted cases

Final Energy Consumption									
	Existing (kWh/m2)			Retrofitted (kWh/m2)			Savings (%)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Heating	153	114	187	76	45	126	51%	63%	33%
Lighting	26	19	31	13	8	21			
DHW			2			3			
Auxiliary			1			1			
TOTAL	183	137	223	93	57	152	49%	59%	32%

Table 12 : Final Energy Consumption of existing and retrofitted cases

CO_2 Emissions (KgCO2eq/m²)									
	Existing (kWh/m²)			Retrofitted (kWh/m²)			Savings (%)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Heating	10	8	13	5	3	8	51%	61%	33%
Lighting	9	7	11	4	3	7			
DHW	0.1			0.2					
Auxiliary	0.4			0.4					
TOTAL	20	15	24	10	6	16	49%	58%	32%

Table 13 : CO_2 Emissions (kWh/m²) of existing and retrofitted cases

2.7 *KPI compliance assessment*

The KPI assessment compares the baseline with the three renovation scenarios for the use case 1 – an office building (3780 m²), using the heated floor area as reference. The indicators cover energy consumption, carbon emissions, energy savings, and net-zero performance.
Table 1 summarizes the main KPIs considered in this deliverable together with their target values.

KPI	Value	Verification
Energy consumption (total final energy)	< 50 kWh/m²/yr	Simulation of energy balance on three use cases across Europe, renovated with EASI ZERo insulation, system (WP6, WP7) and Windows replacement. (total final energy= Heating, DWH, lighting, Auxiliary)
Carbon Emisión (Total Final energy)	< 4 kgCO2/m²/yr	Calculation of CO2 emissions of three renovated buildings, as in energy regulation/standards

		(France RE2020 single family home) (WP6, WP7).
Use case evaluation completed	3	This includes initial performance evaluation, renovation development with EASI ZERo design methodology, performance simulation with full material system after renovation, financial evaluation (WP6, WP7)
Net energy use reduction	-5% absolute minimum	Simulated from building modelling envelope refurbishment. Net energy is situation-dependent, value is absolute minimum obtained (WP6)
Net zero energy for single family house with PV	< 35 kWh/m²/yr	Local PV production is to cover 50% of primary energy needs for a single-family house, including energy storage. This value will not include Nordic climate zone, for which we expect a target at 45 kWh/m²/yr (WP6).

The KPI results are reported in the table below

KPI	Unit	Target value	Baseline	Scenario 1 (envelope)	Scenario 2 (envelope+ Systems)	Scenario 3 (envelope+ Systems)
Energy consumption	kWh/m²/year	**< 50**	131	48	38	38
Carbon emissions	kgCO2/m²/year	**< 4**	15	10	6	4
Net energy use reduction	%	**-5**	-	64%	71%	74%
Net zero energy with PV	kWh/m²/year	**< 35**	-	-	-	34

Table 14 : Use case 1 KPI Results

The KPI assessment highlights a substantial improvement in building performance across the renovation scenarios. Energy consumption decreases significantly from 131 kWh/m²/year in the baseline to 48 kWh/m²/year in Scenario 1, already meeting the target value of 50 kWh/m²/year. Further improvements are observed in Scenario 2 and Scenario 3, reaching 38 and 34 kWh/m²/year respectively, confirming the effectiveness of combining envelope measures with system upgrades.

A similar trend is observed for carbon emissions, which are progressively reduced from 15.5 $kgCO_2/m^2/year$ in the baseline to 4.5 $kgCO_2/m^2/year$ in Scenario 3. Although the emissions decrease substantially, the target value of 4 $kgCO_2/m^2/year$ is not fully achieved. This is mainly due to the carbon intensity of the German electricity mix used in the assessment, which may differ from one country to another. Therefore, additional measures may be required to further decarbonize the building and reach the target value.

The net energy use reduction shows strong performance for all renovation scenarios, with savings ranging from 64% to 74% compared to the baseline. This largely exceeds the minimum requirement and demonstrates the high impact of the proposed renovation strategies.

Finally, the net-zero energy KPI is achieved in Scenario 3, with a value of 34 $kWh/m^2/year$. In this scenario, the energy consumption already includes the contribution of PV production, resulting in a net energy demand below the defined threshold. This confirms that the combination of energy efficiency measures and on-site renewable energy is necessary to reach net-zero performance.

3. Use case n°2: Saint-Gratien, France

3.1 *Introduction*

A building energy model (BEM) for use cade 2 is developed to represent the thermal behaviour and energy use of the dwelling, serving as a basis for scenario analysis. Considering the project constraints, including the relocation of the case study and delays in the monitoring campaign, the model is positioned as a representative analytical tool rather than a fully calibrated reproduction of the building's actual operational behaviour. It provides a meaningful approximation based on the available information, combining partial on-site measurements, design data, and standard assumptions. These assumptions are derived from a combination of European standards ((ISO E.) and (EN16798-1) national regulatory frameworks such as RE2020, and established literature (IEA), complemented by project-specific data and on-site observations. As in use case 1, the parametric sensitivity analysis for use case 2 is based on the Standardized Regression Coefficients (SRC) method to quantify the influence of selected input parameters on the energy performance indicators. The same approach is applied to ensure a structured interpretation of the results for both the initial and renovated configurations. For each case, the variability of the outputs is described through minimum, maximum, and average values, reflecting the range of plausible energy demand and associated emissions. A reference configuration, defined by mean input values, is also used to enable a consistent comparison between the initial situation and the EZ0 renovation scenario.

3.2 *Case Study Description*

The residential building, located in Saint-Gratien, France, has a total floor area of approximately 3158 m^2 and comprises 42 dwellings. The building is primarily oriented along an East–West axis. Constructed in the 1970s, it consists of five residential floors above a basement level housing storage cellars and technical rooms. The building is topped by a flat roof with limited original insulation. The construction system is characteristic of mass housing developments from the 1950s to the 1970s in France, which relied heavily on prefabrication to enable rapid and large-scale construction. It is

composed of reinforced-concrete load-bearing floors, internal structural walls, and gable walls and façades made of prefabricated panels, combined with infill window elements between structural slabs. These sandwich panels consist of concrete sections incorporating either an air gap or insulation, with an external finish made of colored mosaic tiles. An external view of the building is presented in Figure 6.



Figure 7: Digital model of the Demo 2 Apartment building

Table 16 provides an overview of the building's geometric characteristics, including zone volume, floor area, and the envelope exposure through external walls and openings.

Parameter	Value
Total building volume	8,454 m³
Total floor area	3,158 m²
External wall area	1,686 m²
External opening area	364 m²
Building height	13 m
Number of windows	184

Table 15 : Main geometric characteristics of the use case 2 building

The building is equipped with condensing boilers installed in 2011, ensuring heat production for dwellings. Heat emission is provided through underfloor heating systems, allowing for low-temperature and homogeneous heat distribution. During the site visit, key characteristics of the heating system including installed capacity, heating setpoint (day / night) (°C), system efficiency, and thermostat operating schedules were collected and subsequently used as input data for the building energy model. Domestic hot water (DHW) is produced individually in each dwelling using electric systems. The main characteristics such as storage volume, technical specifications also documented during the on-site survey and integrated into the modelling assumptions.

The building operates with a natural ventilation system based on masonry ducts. A blower door test was conducted to assess the airtightness performance. In addition, in-situ measurements of the thermal transmittance (U-values, W/m²·K) were carried out for both external walls and windows to better characterize the envelope properties.

Internal gains, occupancy schedules, and lighting profiles were primarily collected during site visits and through exchanges with occupants and building stakeholders. Where direct data were not available, parameters were complemented with reasonable assumptions based on standard practices and reference values. In particular, the thermal transmittance (U-values) of building elements for which no direct measurements were available such as the ground floor slab and the roof were estimated based on typical construction practices for residential buildings from the 1970s, using reference values from standards (ISO, 2005) and national regulations (RE2020) as well as data from literature and building typology databases. Occupancy-related parameters, including occupancy density, was defined based on standard residential profiles from (EN16798-1) and supporting literature, assuming typical dwelling usage patterns. Sensible heat gains per occupant were derived from established reference values (ASHRAE) typically ranging around 70–100 W per person depending on activity level. And finally, lighting power density and schedules were also estimated using standard benchmarks from regulatory frameworks and literature, reflecting typical residential lighting usage.

3.3 *Representative Baseline Model*

Baseline model input dataset

A building model was created and analysed in IESVE; the corresponding input data are listed below.

Building envelope assumptions

Designation	Contact	Type	Resistance (m²·K/W)	U (W/m²·K)
Exterior walls	Exterior	Slab-column structure-concrete	0.56	1.48
Roof	Exterior	Concrete flat roofs, gravel-covered – poorly insulated	0.78	1.91
Floor	Basement	Concrete	0.32	2.6
Leakage level ACH		1.04		

Table 16 : Use case 2 - Thermal and airtightness characteristics of the existing building envelope

Windows performance

U window	
Frame type	PVC
Glazing type	double glazing
Uw (W/m²·K)	2.6
U frame (W/m²·K)	2.3

g-value (Solar energy transmittance)	0.71

Table 17 : Use case 2 - Characteristics of the existing windows

Internal gains and occupancy schedules were defined based on questionnaires collected from the co-owners, allowing the integration of realistic occupant behaviour into the simulation model. The residential building was divided into several functional spaces, including bedrooms, living room, kitchen, bathroom, and WC, each associated with specific occupancy patterns and usage schedules. For the living room, internal gains associated with occupants, lighting, and household equipment were explicitly considered in the simulation model. Occupant-related gains were defined using an occupancy density of 10 m²/person, with metabolic gains set to 70 W/person sensible and 30 W/person latent, based on typical residential activity levels. Lighting gains were assigned at 5 W/m² to represent the installed lighting systems, while miscellaneous equipment gains, including domestic appliances and plug loads, were set to 3 W/m². All internal gains were coupled with weekly occupancy schedules derived from questionnaires collected from the co-owners, allowing the model to reflect realistic occupancy patterns and room usage conditions.

Heating and DHW of this use case are provided by a centralized system composed of two gas-condensing boilers, *VIESSMANN Vitocrossal*, with a heating capacity ranging between 200 and 400 kW each and a seasonal efficiency of 93%. The indoor temperature setpoint is regulated at 20°C, with a night setback temperature reduced to 17°C. These technical characteristics were identified during the site visit and inspection of the boiler room. The heating plant is shared between the use case 2 building and another neighbouring residential building, supplying both buildings through a common hydronic network. Space heating is delivered through an old low-temperature underfloor heating system operating with supply temperatures of approximately 46°C at an outdoor temperature of −5°C and 26°C at an outdoor temperature of 15°C. Domestic hot water production is provided by individual electric water heaters installed in the apartments. In the simulation model, the DHW system was represented using electricity as the energy source, with demand profiles based on occupancy schedules from questionnaires.

Natural ventilation was modelled using the MacroFlo module in IESVE in order to represent airflow exchanges through window openings and infiltration paths under realistic operating conditions. The openings were defined according to the building geometry and façade configuration, with opening schedules based on occupant behaviour.

3.3.1 Use case 2: Baseline results

The heat balance indicates that heat losses are mainly associated with the building envelope and air renewal. Losses are almost equally shared between the five main areas: external walls, windows, floors, roofs, and air renewal. Heat losses through doors remain almost negligible. Overall, the total heat loss is estimated at 368 MWh.

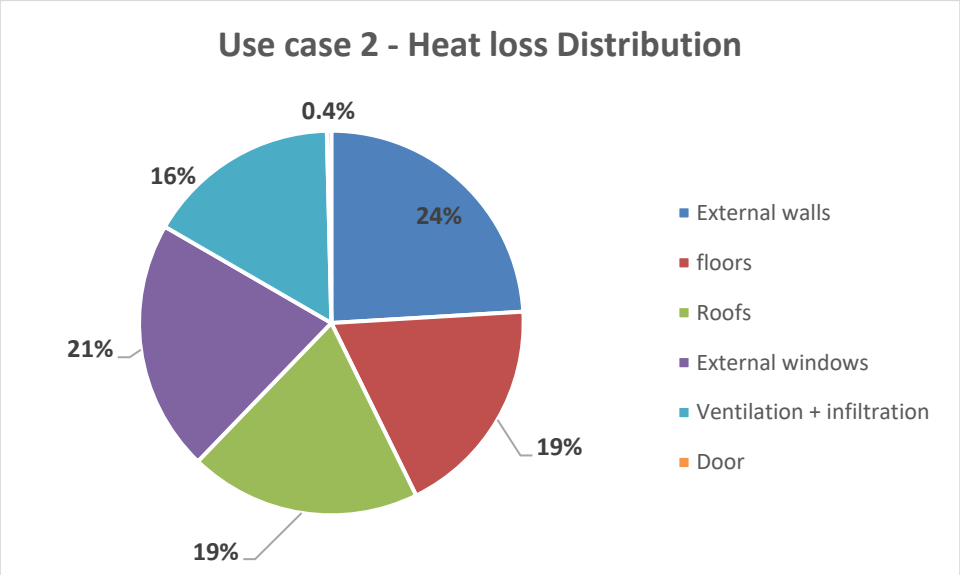


Figure 8 : Use case 2- Heat loss Distribution

The energy consumption results are presented in the table below.

End use category		Final Energy Consumption [kWh]		End use category		CO_2 emissions [kg.CO_2]	
		Gas	Electricity			Gas	Electricity
Heating		**224 726**		**Heating**		**51 012**	
Domestic hot water			**137 622**	**Domestic hot water**			**10 872**
Lighting			**28 185**	**Lighting**			**2 226**
Auxiliaries			**4 090**	**Auxiliaries**			**323**
Total	**[kWh]**	**394 620**		**Total**	**[kgCO_2]**	**64 435**	
	[kWh/year/m²]	**125**			**[kgCO_2/year/m²]**	**20**	

Table 18 : Baseline of use case 2- Energy Consumption and CO_2 emissions

The baseline results for use Case 2 show that the building has a total final energy consumption of 394,620 kWh/year, corresponding to 125 kWh/m²/year. Heating represents the largest share of the energy demand, followed by domestic hot water and electricity uses such as lighting and auxiliaries. The associated annual CO_2 emissions amount to 64,435 kgCO_2/year, equivalent to 20 kgCO_2/m²/year. These results define the baseline situation against which the refurbishment scenarios are compared. The CO_2 emissions were calculated using emission factors of 0.227 kgCO_2/kWh for gas (legifrance, s.d.) and 0.079 kgCO_2/kWh for electricity (legifrance, s.d.).

3.4 *Renovation Scenario Modelling*

As described for use case 1, the same methodological approach was followed for the development of renovation scenarios for use case 2. A multicriteria analysis was carried out to evaluate the potential integration of EZ0 materials within the existing residential building. Each material was assessed according to its compatibility with the building envelope, construction systems, and potential application areas, while also considering the technical feasibility of the proposed interventions.

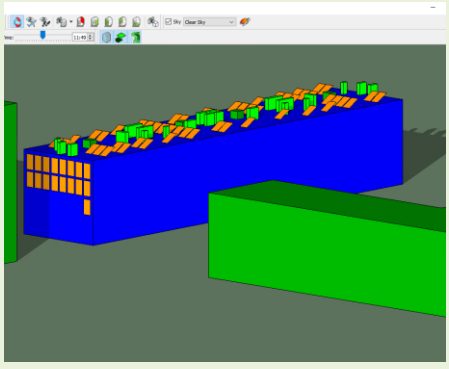
Unlike use case 1, this building does not present heritage-related restrictions, which allows external insulation solutions to be considered in addition to interior interventions. Moreover, since the building is occupied, the proposed renovation strategies were developed in line with common practices typically applied to inhabited residential buildings. In this context, external insulation appears to be the most relevant and feasible solution, as it can significantly improve the thermal performance of the envelope while minimizing disturbance to occupants. In contrast, internal insulation would require major interventions inside the apartments, often involving the temporary relocation of residents and the removal or adaptation of interior finishes and furniture. Therefore, the renovation scenarios developed for use case 2 primarily prioritize external envelope interventions that are compatible with occupied-site renovation practices.



Figure 9 : Main façade of use case 2

For use case 2, a similar scenario-based approach was adopted to evaluate the potential achievement of the targeted KPIs under different levels of renovation intervention. Three renovation scenarios were developed progressively. The first scenario focuses on improvements to the building envelope only, mainly through external insulation measures and window replacement, with the objective of reducing the heating demand of the existing building. The second scenario extends this approach by integrating the replacement of the existing heating system with a heat pump solution, allowing the assessment of the impact of system decarbonization on overall energy performance and CO_2 emissions. Finally, the third scenario incorporates renewable energy production through the installation of photovoltaic panels on the roof and, where technically feasible, on selected façade areas, to further improve the building's energy balance and move closer

to the project performance targets, it also includes the replacement of the existing domestic hot water system with individual heat pump water heaters. Although this DHW replacement option may not be technically feasible in practice for this case study, it was nevertheless assessed to explore whether it could contribute to achieving the targeted KPIs. The renovation measures considered for each scenario are summarized in the following table.

Variants	EZ0 Products
V1 – Opaque Envelope	• External Walls: Sprayable Low density Bio-PUR foam, 300 mm • Floor: Wood-fibre insulation panel in wall assembly, 220mm • Roof: Wood-fibre insulation panel in wall assembly, 220 mm
V2 - Windows	• Window with bio PUR paint Uw =1.2W/m²K
V3 – Heat Pump	• Installation of Heat pump of 70 kW
V4 – thermodynamic DHW tank	• Replacement of individual electric domestic hot water tanks with individual heat pump water heaters. (seasonal COP= 2.5) • Electric back-up resistance for peak demand and anti-legionella cycles
V5 – Photovoltaic System	• Installation of photovoltaic panels on the roofs, and PV tiles on attic roofs. Rooftop photovoltaic system: 51 PV panels with an installed capacity of 24.99 kWp, covering a total area of 112.78 m². Façade photovoltaic system: 17 PV panels with an installed capacity of 6.86 kWp, covering a total area of 30.96 m². 

The results presented in Table 24 and table 25 illustrate the evolution of energy demand and CO_2 emissions between the baseline case and the proposed renovation scenarios. All energy values expressed in kWhFE/m² refer to the conditioned gross floor area of the building.

In Scenario 1, significant reductions in heating energy demand are achieved through improvements to the building envelope only. The implementation of external insulation measures and window replacement substantially decreases heat losses through the envelope, leading to a strong reduction in gas consumption for space heating. As a result, the total final energy consumption decreases from 125 to 701 kWhFF/m², corresponding to an energy saving of approximately 44% compared to the baseline case.

Scenario 2 further improves the building's performance through the replacement of the existing gas boiler with a heat pump system. Although the heating demand of the building remains similar to Scenario 1, the change in the heating production system significantly modifies the energy carrier distribution, replacing gas consumption with electricity use for space heating. This transition results in a further reduction of the total final energy consumption to 60 kWhFE/m², corresponding to an overall reduction of approximately 52% compared to the existing case.

Finally, Scenario 3 integrates on-site renewable energy production through the installation of photovoltaic panels on the roof and selected façade areas. The electricity generated by the PV system contributes to offsetting part of the building's electrical consumption, further improving the overall energy balance. Consequently, the total final energy consumption is reduced to 50.56 kWhFE/m², representing an overall reduction of approximately 60% relative to the baseline scenario.

A similar trend is observed for CO_2 emissions across the different renovation scenarios. In Scenario 1, the reduction in heating demand achieved through envelope improvements leads to a significant decrease in gas-related emissions, reducing total CO_2 emissions from 20 to 8 $kgCO_2/m^2$/year. Scenario 2 further improves the environmental performance of the building through the replacement of the gas boiler with a heat pump system, resulting in a substantial reduction in heating-related emissions despite the increase in electricity consumption. Finally, Scenario 3 achieves the lowest CO_2 emissions, reaching 3.99 $kgCO_2/m^2$/year.

		Energy Consumption [kWhFE]			
		Baseline	**Scenario 1** (envelope)	**Scenario2** (envelope+ systems)	**Scenario3** (envelope+ systems)
Energy uses		**V0**	**V1+V2**	**V1+V2+V3**	**V1+V2+V3+V4+V5**
Heating	Gas	224,726	52,905	_	-
	Elec	-	-	20,279	20,279
DHW	Elec	137,622	137,622	137,622	61,241
Lighting	Elec	28,185	28,185	28,185	28,185
Auxiliary systems	Elec	4,090	4,090	4,090	4,090

PV production		-	-	-	**-31,024**
Total kWhFE		**394,620**	**222,802**	**190,706**	**82,771**
kWhFE/m²		**125**	**71**	**60**	**26**
Savings			**-44%**	**-52%**	**-79%**

Table 19 : Use case 2 - Results of Energy Consumption and Energy Savings for the Baseline and Retrofit Scenarios

CO_2 emissions [$kgCO_{2eq}$]					
		Baseline	**Scenario 1** (envelope)	**Scenario2** (envelope+ systems)	**Scenario3** (envelope+ systems)
Energy uses		**V0**	**V1+V2**	**V1+V2+V3**	**V1+V2+V3+V4**
Heating	Gas	51,012	12,008	-	-
	Elec	-	-	1,602	1,602
DHW	Elec	10,872	10,872	10,872	4,838
Lighting	Elec	2,226	2,226	2,226	2,226
Auxiliary systems	Elec	323	323	323	323
PV production	Elec	-		-	**-2,450**
Total $kgCO_{2\ eq}$		64,435	25 430	15,066	**6,538**
$KgCO_{2\ eq}/m^2$ / year		**20.4**	**8.&**	**4.7**	**2.1**

Table 20 : Use case 2 - Results of CO2 emissions for the baseline and retrofit scenarios

3.5 *Parametric study*

3.5.1 Introduction

Although several on-site measurements were conducted for this use case, some key parameters remain uncertain, particularly those related to the thermal properties of the roof, floors, and windows, as well as occupancy density. These variables can significantly influence the model outputs and therefore require further investigation. In line with the approach adopted for use case 1, a sensitivity analysis was performed to assess the impact of these parameters on the baseline model results. This analysis aims to better understand the influence of remaining uncertainties and to strengthen the robustness and reliability of the simulation outcomes for use case 2.

3.5.2 Sensitivity analysis for Use case 2

The table below summarizes the parameters selected for the parametric study of use case 2, along with their corresponding values for both the existing and refurbishment cases, as well as the variation ranges considered for the analysis. To this end, a set of uncertain parameters was defined within the IESVE model. The analysis was conducted for both pre-renovation and post-renovation scenarios. The selected variables are specific to the studied model and its components, including key aspects such as the thermal transmittance (U-values) of the building envelope (roof, floor, and windows), as well as internal gains and occupancy-related parameters. The sensitivity analysis conducted for use cae 2 adopts the same approach as that applied to use case 1, relying on multiple linear regression of the parametric simulation results. This method allows for the identification and prioritization of the input parameters that most strongly influence the selected performance indicators, with particular emphasis on heating demand, overall energy consumption, and CO_2 emissions. To ensure consistency, standardized regression coefficients (SRC) are used to assess the relative influence of each variable, while the statistical significance and reliability of the model are evaluated through p-values and adjusted R^2. The analysis is based on the parameter ranges presented in Table 17.

		Use Case 2				
Variable name	Unit	Existing case	Refurbishment case	Var. 1	Var. 2	Var. 3
Roof U-value	W/m²K	1.9	0.15	Existing: 1.6/1.9/2.5 Refurb:0.13/0.15/0.17		
Floor U-value	W/m²K	2.5	0.14	Existing: 2.2/2.8 Refurb:0.12/0.16		
Window U-value		2.6	1.2	Existing: 2.3/2.6/3 Refurb 1.1 /1.2/1.3		

Occupancy Density	m^2/p	15	15	10	15	20
People max sensible gain	W/ p	60	60	60	70	75
Lighting	W/m^2	5	5	3	5	7
Miscellaneous	W/m^2	3	3	1.5	2	3

Table 21 : Use case 2-Variables for sensitivity analysis

The sensitivity analysis was performed through 1458 simulations in IESVE. Figures 7 and 8 present the results for the existing case, showing the impact of input parameters on heating loads.

The results indicate that heating demand is influenced by both building envelope characteristics and internal gains. Among the envelope parameters, window, roof, and floor show comparable and statistically significant positive impacts, with SRC values of 0.407, 0.395, and 0.374 respectively, all associated with very low p-values (≤ 0.002), confirming their strong influence. However, occupancy density clearly stands out as the most influential parameter, with the highest SRC value (0.708) and a very low p-value (0.001), indicating a dominant and statistically significant contribution. In contrast, People Max Sensible Gain exhibits a significant negative effect (SRC = -0.408, p-value = 0.001), confirming that increased internal gains from occupants reduce heating needs. On the other hand, Miscellaneous Sensible Gain (SRC = -0.098, p-value = 0.08) and Lighting Power Density (SRC = -0.09, p-value = 0.12) have relatively low SRC values and higher p-values, indicating that their effects are weak and not statistically significant in this analysis.

Overall, the high coefficient of determination (R^2 = 0.88) demonstrates that the regression model provides a good representation of the factors influencing heating demand in the existing building.

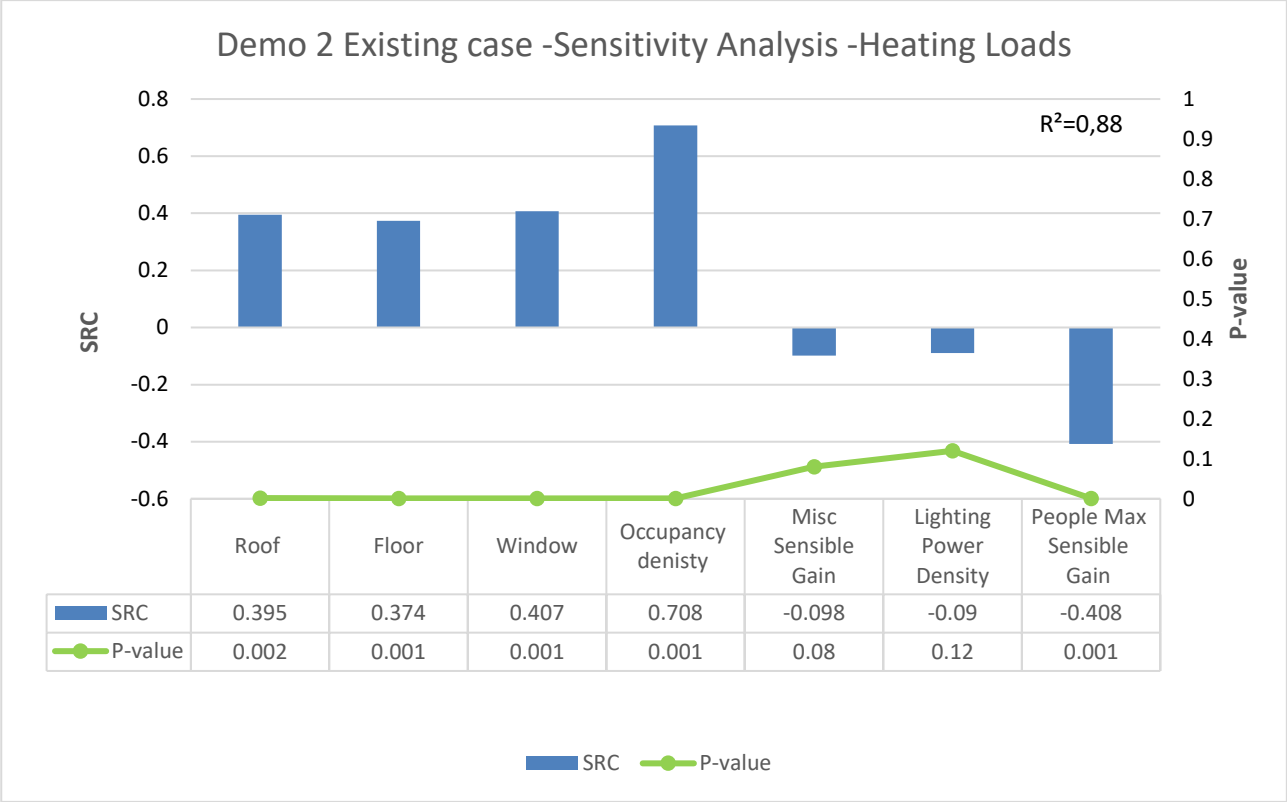


Figure 10 : Sensitivity analysis for heating loads - use case 2 existing case

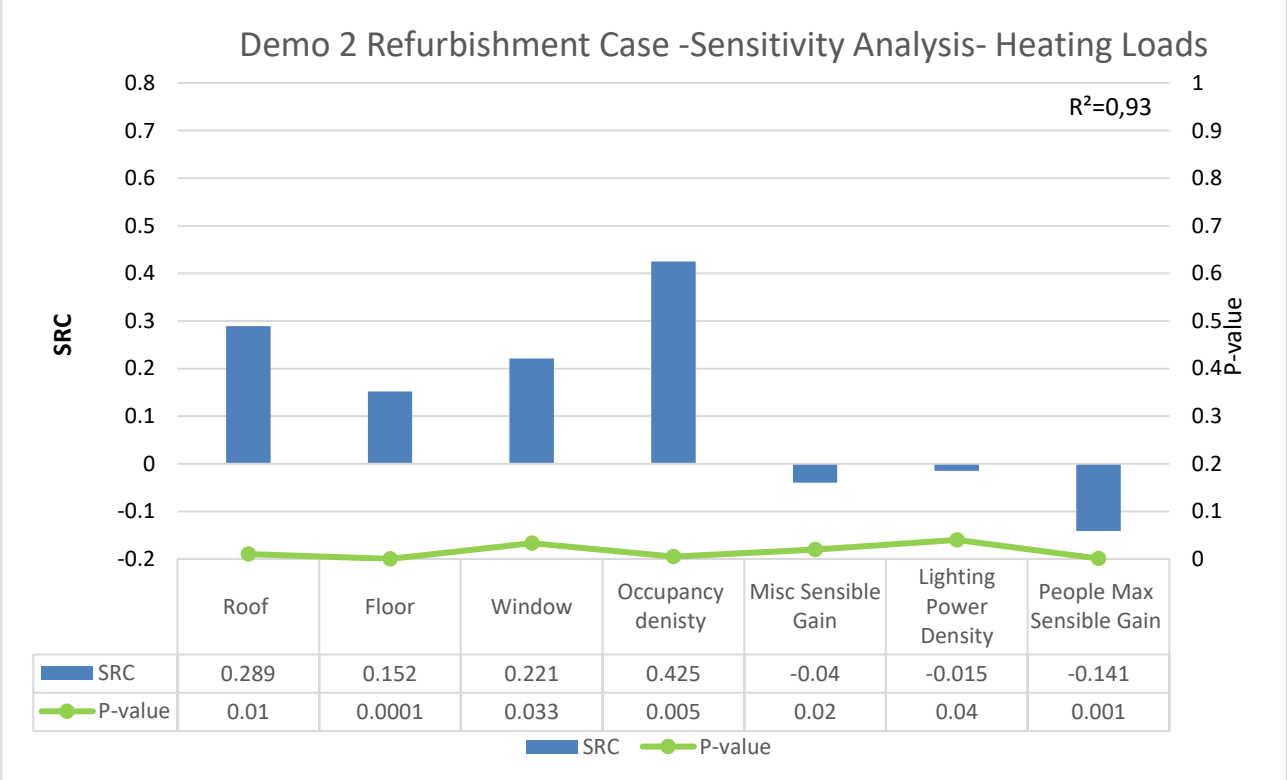


Figure 11 : Sensitivity analysis for heating loads - use case 2 refurbishment case

As shown in Figure 8, the refurbishment case presents trends that are broadly consistent with the existing case, although the magnitude of the SRC values is generally reduced. Occupancy density remains the most influential parameter, with the highest SRC value, indicating that variations in occupant density still play an important role in heating demand. Envelope parameters, particularly the roof, window and floor U-values, also show positive effects, but their influence is lower than in the existing case due to the improved thermal performance of the refurbished envelope.
People Max Sensible Gain shows a negative coefficient, confirming that higher occupant-related internal gains reduce heating needs. Miscellaneous sensible gains and lighting power density also have negative coefficients, but their SRC values remain very low, indicating a limited practical influence despite their statistical significance.

3.5.3 Results for use case 2

The boxplot shows (figure 9) a significant reduction in annual heating loads after refurbishment.
The existing case presents higher median values and a wider distribution, ranging approximately from 60 to 105 kWh/m², whereas the refurbishment case decreases to about 13–56 kWh/m². This indicates that the retrofit measures substantially improved the thermal performance of the building and reduced heating energy demand variability. In addition, the dispersion of results is smaller in the refurbishment case, indicating a more stable and less sensitive energy behavior.
The sensitivity analysis results show that the heating energy consumption decreased from an average of 87 to 32 kWh/m², corresponding to average energy savings of 62%, while total energy consumption was reduced by 38%. Similarly, total CO_2 emissions decreased from 25 to 12 kgCO_2/m², representing average savings of 51%.
The sensitivity analysis demonstrates that the building's energy performance strongly depends on the selected variables, which may either enhance or reduce the achieved savings. Parameters related to the thermal envelope, such as roof, floor, and window U-values, showed the strongest impact on heating demand and overall energy consumption. In contrast, lighting energy consumption exhibited only minor variation between the existing and retrofitted cases, since lighting represents a relatively small share of the total building energy use and mainly depends on operational schedules and lighting power density rather than envelope thermal characteristics. Moreover, lighting gains contribute to internal heat gains, partially offsetting heating demand.

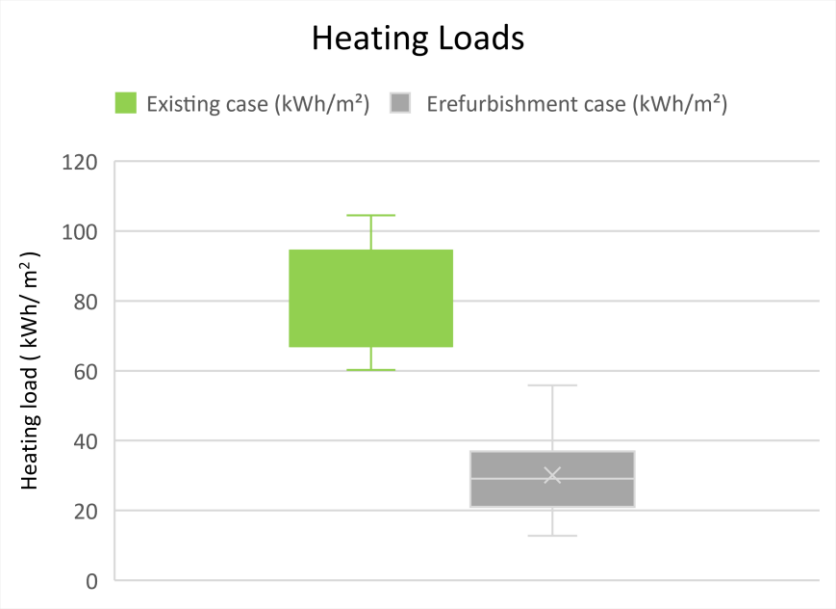


Figure 12 : Heating distribution – use case 2 Sensitivity analysis.

Thermal Energy Demand (KWh/m²)								
Existing			Retrofitted			Savings (%)		
Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
80	60	104	30	12	56	62	45	79

Table 22 : Use case 2 - thermal Energy Demand

Final Energy Consumption									
	Existing (kWh/m²)			Retrofitted (kWh/m²)			Savings (%)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Heating	87	65	112	32	14	60	62%	79%	47%
Cooling									
Lighting	10			11			-4%		
DHW	50			48			4%		
Auxilary	2			2					
TOTAL	148	127	174	93	74	120	38%	42%	31%

Table 23 : Use case 2 sensitivity analysis - final energy consumption

CO2 Emissions									
	Existing ($kgCO_2/m^2$)			Retrofitted ($kgCO_2/m^2$)			Savings (%)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Heating	19.63	14.70	25.49	7.36	3.12	13.62	62%	79%	47%
Cooling	-			-			-		
Lighting	1			1			-4%		
DHW	4			4			4%		

Auxliary			0.1			0.1			
TOTAL	25	19	30	12	7	18	51%	62%	41%

Table 24 : Use case 2 Sensitivity analysis - CO2 emissions

3.6 *KPI compliance assessment*

The results show that the first KPI related to final energy consumption (< 50 kWh/m²·year) is not fully achieved in Scenarios 1 and 2, despite the significant reductions obtained through envelope renovation and the integration of the heat pump system. This remaining gap is mainly explained by the relatively high electrical consumption associated with domestic hot water production and lighting, which continue to represent an important share of the building's overall energy demand. In Scenario 3, the integration of photovoltaic panels significantly and the replacement of the electric DHW storage tank to heat pump water tank improves the building energy balance by offsetting part of the electrical consumption, allowing the energy consumption KPI to be reached with a final value of 26 kWh/m²·year.

KPI	Unit	Target value	Baseline	Scenario 1 (envelope)	Scenario 2 (envelope+ Systems)	Scenario 3 (envelope+ Systems)
Energy consumption	kWh/m²/year	**< 50**	125	71	60	36
Carbon emissions	kgCO2/m²/year	**< 4**	20.4	8	5	2
Net energy use reduction	%	**-5**	-	44%	52%	79%
Net zero energy with PV	kWh/m²/year	< 35	-	-	-	26

Table 25 : Use case 2 - KPIs Results

For the carbon emissions KPI (< 4 $kgCO_2/m^2$·year), scenario 1 already achieves a substantial reduction in emissions through the decrease in heating demand, while, scenario 2 further improves the environmental performance of the building through the replacement of the gas boiler with a heat pump system, bringing the building very close to the targeted threshold with a value of 5 $kgCO_2/m^2$·year. Finally, Scenario 3 achieves the carbon emissions target, with a value of 2 $kgCO_2/m^2$·year, due to the combined effect of envelope improvements, system electrification, DHW system improvement, and on-site renewable electricity production.

Concerning the third KPI, associated with net energy use reduction, all renovation scenarios demonstrate significant improvements compared to the baseline case, with reductions of 44%, 52%, and 79% for Scenarios 1, 2, and 3, respectively. The fourth KPI, related to net zero energy with PV, is achieved only in Scenario 3, with a resulting value of 26 kWh/m²·year, which is below the target threshold of 35 kWh/m²·year.

4. Use case n°3: Trondheim (NO)

Calibration and Assessment of Renovation Materials and BIPV Integration in a Single-Family House in Trondheim, Norway.

4.1 *Introduction*

Use Case 3 evaluates the impact of innovative renovation materials and Building-Integrated Photovoltaics (BIPV) on the operational energy performance of an existing single-family house located in Trondheim, Norway. The assessment was carried out through the development, calibration and application of a dynamic building energy model, supported by monitoring data, building surveys, envelope characterization and occupant behaviour information.
The objective of the use case is twofold:

1. To develop and calibrate a representative building energy model capable of reproducing the actual operational behaviour of the dwelling.
2. To assess the impact of selected renovation products and renewable energy integration on energy consumption and project Key Performance Indicators (KPIs).

The work contributes to validating low-carbon renovation solutions under real operating conditions in cold climatic environments.

4.2 *Building Description*

The case study is a detached single-family house constructed in the 1960s, occupied by two residents (~60 years old). The building has a total modelled floor area of approximately 250 m², distributed over three levels: ground floor, first floor and attic. The overall geometric characterization includes 18 thermal zones, of which 11 are actively heated. All the thermal zones with respective geometries are reported in Table 26.



Figure 13: Digital model of the use case.

Floor	Room ID	Volume	Area	Ext wall area	Ext openings
		m3	m2	m2	m2
Ground floor	guestroom	21.6	8	14.5	0.84
Ground floor	storage	18.2	6.7	7.3	0
Ground floor	living left	17.5	6.5	7	0
Ground floor	living right	33.8	12.5	18	1.1
Ground floor	studio	36.4	13.5	18.4	1.8
Ground floor	entrance	10.7	3.9	3.6	5.4
Ground floor	bedroom	46.4	17.2	19.5	2.9
Ground floor	bathroom corridor	4.8	1.8	0	0
Ground floor	bathroom	7.6	2.8	0	0
Ground floor	toilet	3.6	1.3	0	0
-	stairs	32.2	5.8	0	0
First floor	bedroom	35.1	12.5	18.3	1.6
First floor	bathroom	13.3	4.75	0	0
First floor	laundry room	17	6	10.4	3.8
First floor	kitchen	54.2	19.38	10.8	7.6
First floor	studio	27.7	9.9	15.6	2
First floor	living room	108.4	38.7	43.1	8.4
Attic	attic	92.3	80.24	14.7	1
Totals			251.5	201.2	36.4

Table 26: Building thermal zones geometry

The dwelling does not include an active cooling system; heating is fully electric and provided through a combination of:

- Electric floor heating
- Fixed electric heaters
- Portable electric heaters

Domestic hot water (DHW) is electrically supplied by an OSO RS200 (1998) 200 litres storage tank, equipped with a 2 kW heating element and operated at a delivery temperature of 65 °C. The inlet water temperature was assumed to be 10 °C. The main electrical systems and appliances considered in the simulation model are presented in Table 27.

Category	Subcategory	Element	Monitored	Power (W)	Amount
DHW	Water tank	DHW tank	yes	2,000	1
Heating	Floor heating	Bathrooms + laundry	no	800	3
Heating	Fixed heaters	Living room heater	yes	600	1
Heating	Portable heaters	Studio heater	no	1,500	1
Heating	Fixed heaters	Bedroom heater	yes	600	1
Heating	Portable heaters	Kitchen heater	no	1,500	1

Heating	Portable heaters	Office heater	yes	700	1
Heating	Portable heaters	TV room heater	no	1,000	1
Kitchen	Cooking	Cooktop	no	7,000	1
Kitchen	Cleaning	Dishwasher	no	1,800	1
Kitchen	Cooking	Oven	no	2,500	1
Kitchen	Small appliances	Microwave	no	1,200	1
Kitchen	Ventilation	Extractor fan	no	100	1
Laundry	Washing	Washing machine	no	2,000	1
Lighting	Other	Halogen + others	no	20	13
Lighting	LED	Whole house LED	no	5	32
Living	Audio	Yamaha system	no	200	1
Living	Entertainment	TV	no	120	1
Living	Audio	Audio system	no	150	1
Living	Small devices	Vinyl/CD	no	50	1
Living	Small devices	Printer	no	30	1
Office	Work	Laptop + monitor	no	120	1
Refrigeration	Freezer	Freezer	no	150	1
Refrigeration	Fridge	Kitchen fridge	no	150	1
Refrigeration	Fridge	Storage fridge	no	100	1

Table 27: Systems and appliances considered in the simulation.

4.3 *Renovation Measures and BIPV Integration*

The renovation strategy combines bio-based materials, envelope performance improvements, and renewable energy generation technologies. The selected interventions aim to reduce thermal losses while improving the overall energy balance of the building.

4.3.1 Envelope Renovation Measures

The following renovation products were applied to the building envelope:

- Mycelium-based decorative insulation panels, installed on the internal side of external walls.
- Wood fiber insulation panels, applied on the internal side of the roof structure.
- High-performance renovated windows, replacing the existing glazing systems with improved thermal transmittance and airtightness characteristics.

More accurate product description can be found in deliverable 7.4 “Material passport for new construction products”.
These interventions target the reduction of transmission heat losses, which represent the dominant energy demand component in Nordic climatic conditions.

4.3.2 Renewable Energy Integration

In addition to envelope renovation measures, a Building-Integrated Photovoltaic (BIPV) system was simulated.
The BIPV installation consists of a South-oriented roof integration for Total active area: 48 m².
The objective of the simulation was to estimate the annual on-site renewable electricity production and its contribution to reducing net operational energy demand.

4.4 *Data Collection and Monitoring Campaign*

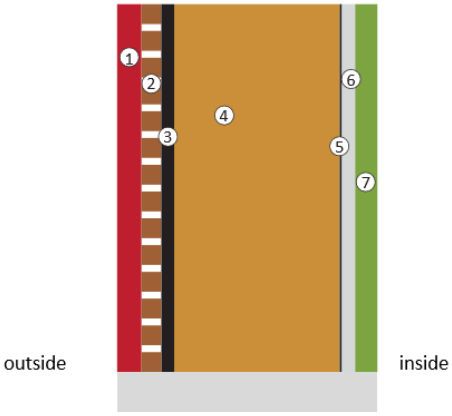
A comprehensive data collection and monitoring campaign was implemented to support model calibration and improve the representativeness of the simulation inputs. The objective was to reproduce the actual operation of the building as accurately as possible before assessing renovation scenarios.

4.4.1 Building envelope

The building envelope was characterized using information from Deliverable 6.1, *Use Case Buildings Baseline, BIM Modelling*, supported by assumptions based on Norwegian construction practices from the 1960s (Norwegian Building Regulations (1969), Chapter 54 – Varmeisolering og tetthet (Thermal insulation and airtightness) and partial renovation works assumed to have been carried out in the 2000s. (TEK97 – Norwegian Technical Building Regulations (1997). TEK07 – Norwegian Technical Building Regulations (2007)). The model walls assemblies are reported in the figures, for practical purposes the renovation layer was also included (in green).

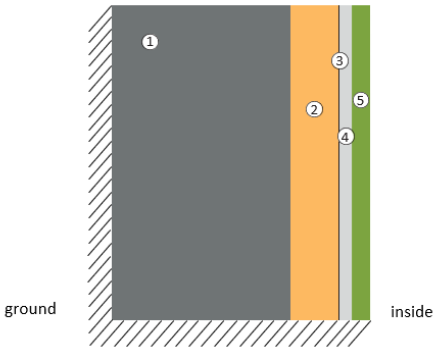
The main envelope elements considered in the model are illustrated below. The stratigraphies refer to the renovated scenario to avoid repetition. Renovation materials are highlighted in green and listed in the table.

- **External Timber Wall**



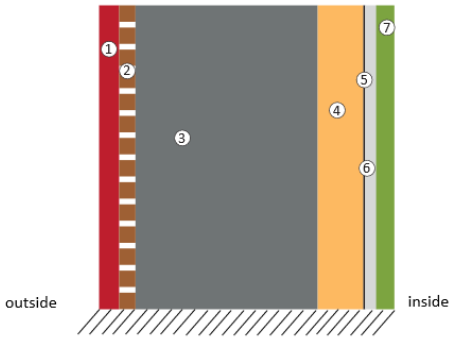
No	Element	Thickness
1	Exterior wood cladding	22 mm
2	Ventilated timber battens	18 mm
3	Wood fiber wind barrier	12 mm
4	Timber stud frame + Mineral wool insulation	150 mm
5	PE vapor barrier	0.2 mm
6	Internal Gypsum board	13 mm
7	Mycelium panel	20 mm

- **External concrete wall (ground contact)**



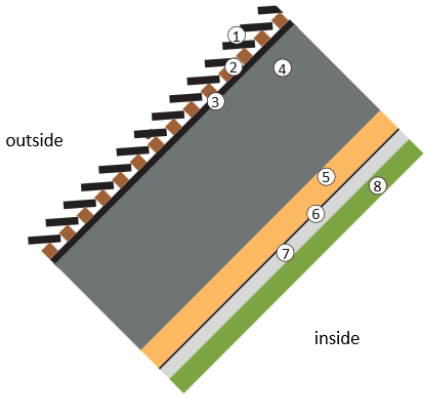
No	Element	Thickness
1	Reinforced concrete wall	200 mm
2	Interior service layer insulation	50 mm
3	PE vapor barrier	0.2 mm
4	Internal Gypsum board	13 mm
5	Mycelium panel	20 mm

- **External concrete wall**



No	Element	Thickness
1	Exterior wood cladding	22 mm
2	Ventilated timber battens	18 mm
3	Reinforced concrete wall	200 mm
4	Interior service layer insulation	50 mm
5	PE vapor barrier	0.2 mm
6	Internal Gypsum board	13 mm
7	Mycelium panel	20 mm

- **Pitched roof**



No	Element	Thickness
1	Clay roof tiles	22 mm
2	Roof battens	13 mm
3	Wind barrier	20 mm
4	Timber rafters	150 mm
5	Interior service layer	50 mm
6	PE vapor barrier	0.2 mm
7	Internal Gypsum board	13 mm
8	Wood panel	20 mm

The envelope assemblies were used as the starting point for the calibration of thermal transmittance, thermal mass and infiltration-related parameters.

4.4.2 Monitored Data

The following variables were monitored and used for calibration:

- Radiator electricity consumption
- Domestic hot water electricity consumption
- Indoor air temperatures
- Room temperatures
- Weather Temperature and Relative humidity
- Whole-building electricity consumption (bills)

The monitoring period with complete data extends from February 2025 to April 2026.

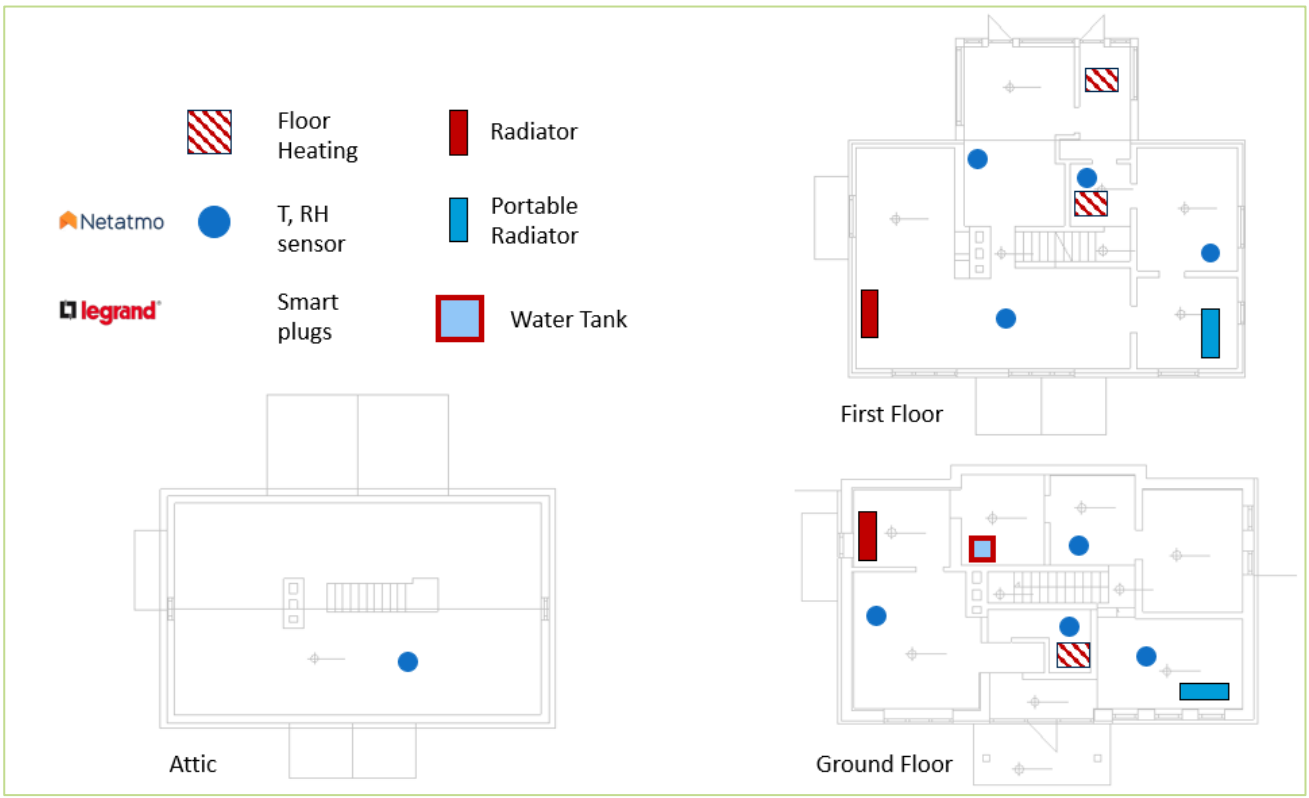


Figure 14: Monitoring scheme

Floor	Room ID	Monitored	Heating system
Ground Floor	Guestroom	No	none
Ground Floor	Storage	No	none
Ground Floor	Living Left	No	none
Ground Floor	Living Right	T, RH	Radiators
Ground Floor	Studio	T, RH	Radiators
Ground Floor	Entrance	No	none
Ground Floor	Bedroom	T, RH	Radiators
Ground Floor	Bathroom Corridor	No	none
Ground Floor	Bathroom	T, RH	Floor Heating
Ground Floor	Toilet	No	none
-	Stairs	No	none
First Floor	Bedroom	T, RH	None
First Floor	Bathroom	T, RH	Floor Heating
First Floor	Laundry Room	No	Floor Heating
First Floor	Kitchen	T, RH	Radiators
First floor	studio	No	Radiatiors
First floor	living room	T, RH	Radiatiors
Attic	attic	T, RH	none

Table 28: Monitoring plan description

4.4.3 Data from survey

Occupant-related parameters were estimated through dedicated surveys, including:

- Appliance power ratings and operational schedules
- Occupancy profiles
- Window opening behaviour
- Solar shading operation patterns

These parameters were used to define realistic internal gains and operational schedules within the simulation model.
As example we report a table from the survey, similar tables are for winter occupancy, appliances, lights, windows and shading behaviour.

SUMMER OCCUPANCY

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
0:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf
1:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf
2:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf
3:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf
4:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf
5:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf
6:00	bathroom	bathroom	bathroom	bathroom	bathroom	bathroom	bathroom
7:00	kitchen	kitchen	kitchen	kitchen	kitchen	kitchen	out
8:00	out	Home office	out	out	out	living-room ff	out
9:00	out	Home office	out	out	out	living-room ff	out
10:00	out	Home office	out	out	out	living-room ff	out
11:00	Home office	Home office	Home office	Home office	Home office	living-room ff	out
12:00	kitchen	kitchen	kitchen	kitchen	kitchen	kitchen	kitchen
13:00	out	Home office	out	out	out	kitchen	living-room ff
14:00	out	Home office	out	out	out	out	living-room ff
15:00	out	Home office	out	out	out	out	living-room ff
16:00	living-room ff	living-room ff	living-room ff	living-room ff	living-room ff	living-room ff	living-room ff
17:00	kitchen	kitchen	kitchen	kitchen	kitchen	out	living-room ff
18:00	kitchen	kitchen	kitchen	kitchen	kitchen	out	kitchen
19:00	tv-room	living-room ff	tv-room	living-room ff	tv-room	out	tv-room
20:00	tv-room	living-room ff	tv-room	living-room ff	out	tv-room	tv-room
21:00	tv-room	living-room ff	tv-room	living-room ff	out	tv-room	tv-room
22:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf
23:00	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf	bedroom gf

Table 29: Weekly summer occupancy schedule

Building Airtightness

A blower door test was conducted to evaluate the airtightness of the building envelope. The measured air leakage rate was:

- n50 = 5.56 h^{-1}

During calibration, this value was used as a reference for defining the infiltration assumptions in the dynamic simulation model.

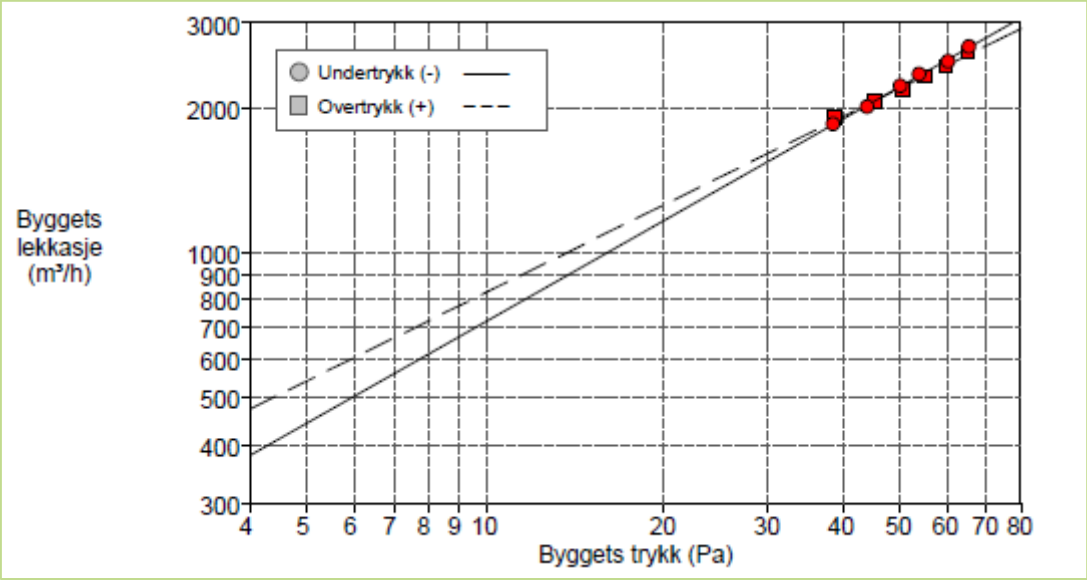


Figure 15: Blower door test results

5Energy Model Development and Calibration Methodology

The building energy model was developed in **IESVE** and calibrated against measured operational data.

The calibration methodology was structured into three sequential phases:

1. System calibration, focused on reproducing electricity consumption from heating systems, DHW and appliances.
2. Envelope calibration, focused on reproducing indoor temperature profiles and envelope thermal behaviour.
3. Full model calibration and validation, combining calibrated systems and envelope assumptions.

This staged methodology was adopted to reduce uncertainty progressively and avoid compensating errors between system operation and envelope performance.

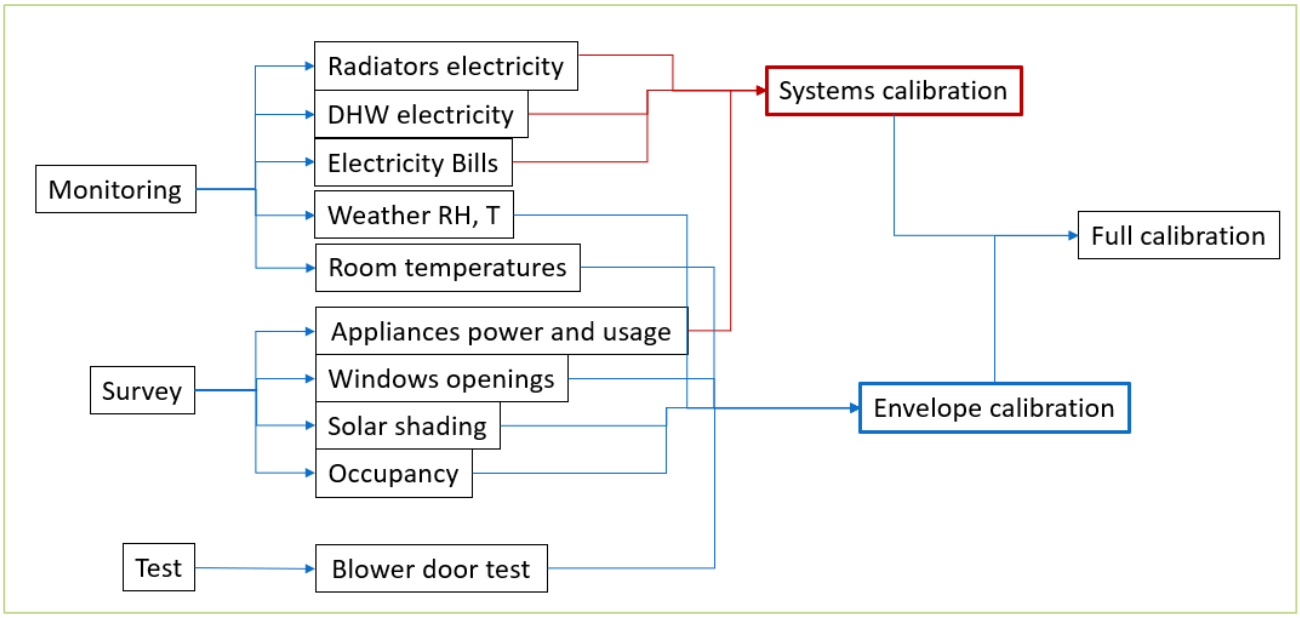


Figure 16: Calibration algorithm scheme

4.5 *System Calibration*

The objective of the system calibration was to reproduce the electricity consumption associated with the building services and occupant equipment.
The calibration process used:

- Radiator electricity consumption
- DHW electricity consumption
- Electricity bills
- Weather temperature and relative humidity
- Appliance usage surveys

A parametric analysis was performed to estimate monthly operational profiles for each electricity-consuming system.
The monitoring period with complete data extends from April 2025 to April 2026.
Equivalent systems were implemented in the simulation environment using simplified operational logic:

- Portable heaters: 1500 W, occupancy and temperature controlled, setpoint 25°C
- Fixed heaters: 600 W, occupancy and temperature controlled
- Floor heating: constant operation at 30°C setpoint, maximum power 800 W

4.5.1 System Calibration Results

The calibrated model estimated a total annual electricity consumption of:

- 20 MWh/year
- Equivalent to 80 kWh/m²/year

The end-use breakdown is:

- Heating: 46 kWh/m²/year
- Appliances: 25 kWh/m²/year
- Domestic hot water: 7 kWh/m²/year
- Lighting: 2 kWh/m²/year

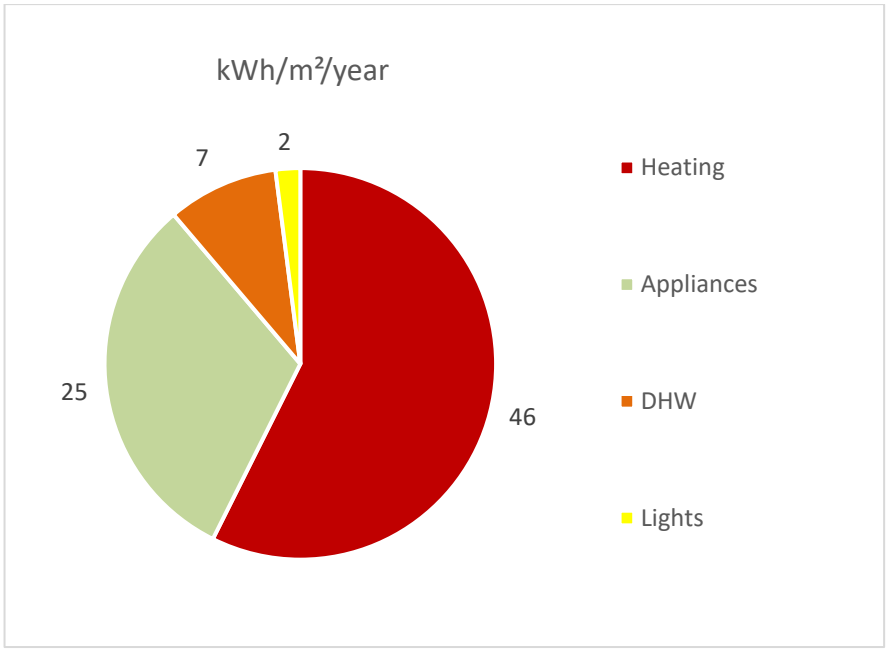


Figure 17: Energy Consumption Distribution

Regarding the heating systems:

- Floor heating: 22 kWh/m²/year
- Portable heaters: 13 kWh/m²/year
- Fixed heaters: 10 kWh/m²/year

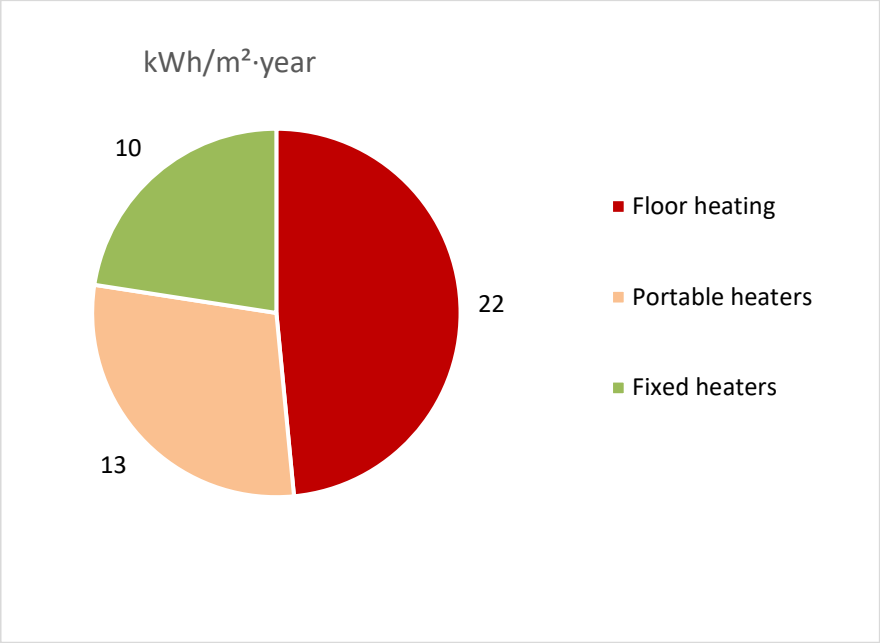


Figure 18: Heating Consumption Distribution.

4.6 *Envelope Calibration*

The envelope calibration focused on reproducing the thermal behaviour of the building envelope. Weather boundary conditions were defined using an EPW file based on the closest reference weather station (Voll, Trondheim), with the key variables outdoor air temperature and relative humidity replaced by the values measured on-site. Where required by the EPW format, the dry-bulb temperature input was derived consistently from the available humidity variables by computing dew point using the Magnus–Tetens formulation (Oleg A. Alduchov. Improved Magnus Form Approximation of Saturation Vapor Pressure. 1996.) and applying the corresponding psychrometric relationships to generate a coherent hourly dataset.
The initial envelope constructions were based on Deliverable 6.1 and used as the starting point for calibration. Internal gains from occupants, appliances and lighting were included in the model but were not directly calibrated.

4.6.1 Free-Floating Calibration

As a preliminary step, free-floating simulations were carried out without active heating. This allowed the envelope response to be assessed with reduced interference from heating system operation.

The free-floating calibration focused on:

- Thermal mass
- Envelope thermal transmittance
- Infiltration assumptions

- Solar gains and shading behaviour

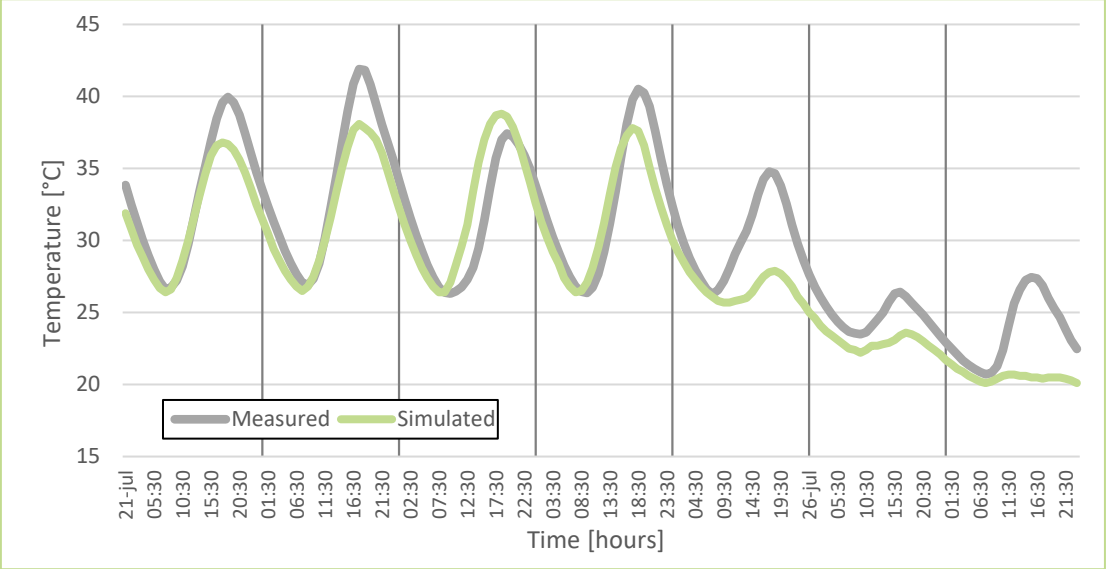


Figure 19: Measured and simulated temperature in the attic during the week of summer solstice (21st to 27th of July).

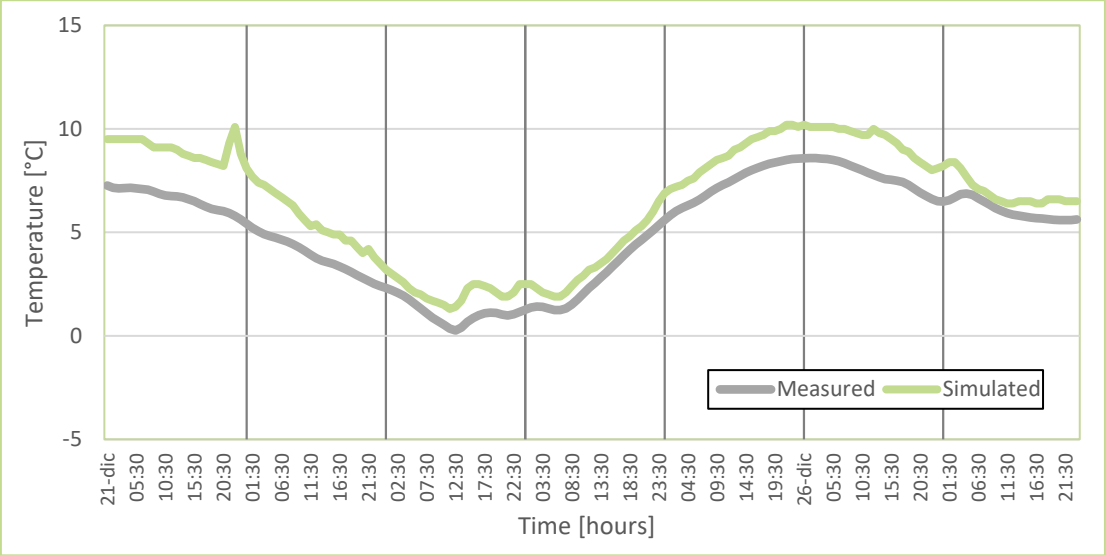


Figure 20: Measured and simulated temperature in the attic during the week of winter solstice (21st to 27th of December).

4.6.2 Seasonal Calibration

Following the free-floating calibration, the equivalent heating systems developed during system calibration were integrated into the model. Seasonal calibration was then conducted for representative summer and winter periods.

This step allowed the combined envelope and system response to be evaluated under both mild and cold weather conditions.

4.7 *Full Calibration and Validation*

The final calibrated model combines the system calibration and envelope calibration results. A multi-parameter optimization process was carried out through iterative simulations to minimize the discrepancy between measured and simulated room temperatures during the summer and winter solstice..

The model validation followed the principles of ASHRAE Guideline 14 [2] using:

- Normalized Mean Bias Error, NMBE < 10%
- Coefficient of Variation of the Root Mean Square Error, CV(RMSE) < 30%

		Summer Week		Winter Week	
Floor	**Room ID**	**NMBE**	**CV(RMSE)**	**NMBE**	**CV(RMSE)**
		%	%	%	%
Ground Floor	Living Right	2.1	14	3.8	18
Ground Floor	Studio	4.9	24	6.8	28
Ground Floor	Bedroom	5.9	27	7.9	30
Ground Floor	Bathroom	4.2	16	4.7	21
First Floor	Bedroom	3.7	19	5.5	24
First Floor	Bathroom	3.9	15	4.3	20
First Floor	Kitchen	6.7	26	7.4	30
First Floor	Livingroom	5.7	26	7.5	29
Attic	Attic	2.8	17	4.2	22

Table 30: Calibration accuracy indicators for room temperatures (NMBE and CVRMSE).

4.7.1 Calibrated envelope properties

The calibrated U-values adopted in the final model are reported below.

		U initial	U calibrated
External timber wall	**W/m²K**	0.34	0.4
External concrete wall	**W/m²K**	0.65	0.68

Ground contact concrete wall	**W/m²K**	0.65	0.7
Pitched roof	**W/m²K**	0.34	0.42
Windows	**W/m²K**	1.6	1.6

Table 31: Initial and calibrated envelope values.

Airtightness, window operation, and shading behaviour were also adjusted during calibration. A blower door test measured an air permeability of n50 = 5.56 h^{-1} at 50 Pa. This value was used to estimate the building's natural infiltration rate, which was further adjusted during calibration to improve the agreement between measured and simulated indoor temperatures, resulting in a final infiltration rate of 0.30 ACH under normal operating conditions.

4.8 *Renovation Scenario Assessment*

The calibrated model was subsequently used to evaluate the impact of the renovation measures.

4.8.1 Impact of Envelope Renovation

After applying:

- Mycelium insulation panels to the interior of the external walls
- Wood fiber roof insulation, on the interior of the roof
- Renovated high-performance windows.

The heating demand decreased from:

- **46 kWh/m²/year** to **25 kWh/m²/year**

This corresponds to an approximate:

- **45% reduction in heating energy demand**

4.9 *Efficient User Behaviour Scenario*

An additional scenario was analysed to evaluate the influence of occupant behaviour on energy consumption. We noticed a too high setpoint 30 °C in the bathrooms conditioned with floor heating and it was always on.
The analysis showed that reducing the floor heating setpoint temperature to **19°C** results in:

- Approximately **47% additional reduction** in heating consumption.

Combining renovation measures and efficient user operation results in:

- Final heating demand: **16 kWh/m²/year**

This corresponds to:

- Approximately **65% reduction** compared to the baseline scenario.

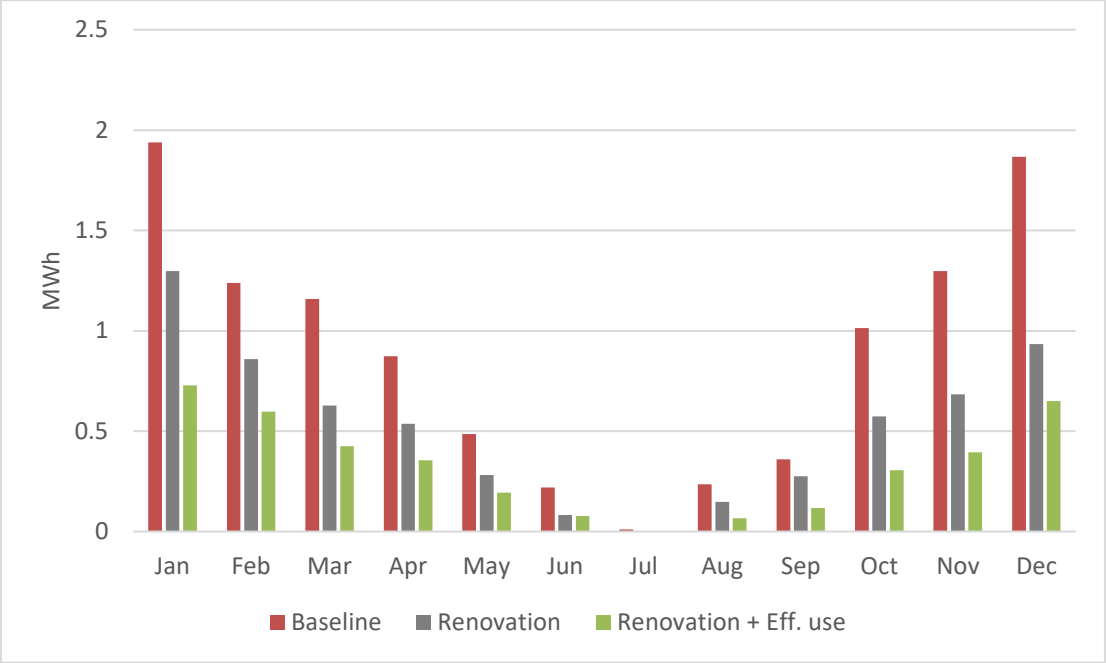


Figure 21: Comparison of baseline, renovated, and efficient-use scenarios.

4.10 *BIPV Energy Production Assessment*

The BIPV system installed on the south-oriented roof surface was simulated to estimate annual electricity generation.
The simulation results indicate an annual renewable electricity production of:

- 18 kWh/m²/year

The present analysis does not include:

- Electrical storage systems
- Grid export/import dynamics

Nevertheless, the results demonstrate the significant contribution of on-site renewable energy generation toward reducing net operational energy demand. The figure below shows the energy consumption for the renovation and efficient use scenario (R+EU) and the photovoltaic production (PV) with monthly resolution through the year.

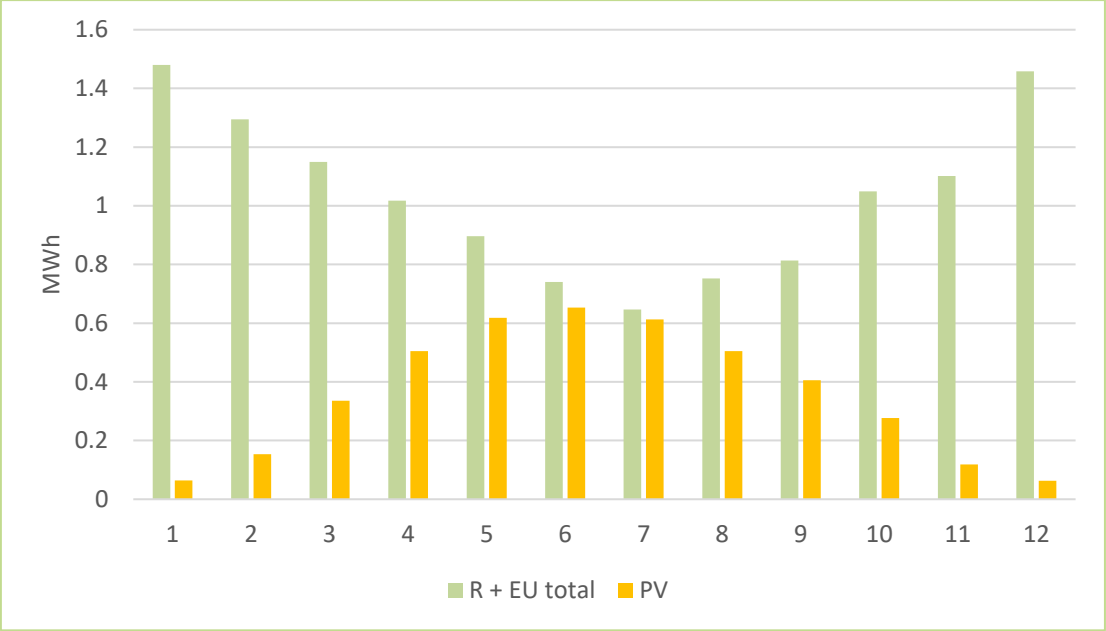


Figure 22: Annual consumption after renovation and efficient usage measures and BIPV production.

4.11 *KPI Assessment*

The simulation results were evaluated against the project performance targets.

KPI	Unit	Target Value	Baseline	Renovated envelope	Renovated envelope + efficient use
Energy Consumption	kWh/m²/year	< 50	79,7	59,2	49,6
Carbon Emissions	kgCO2/m²/year	< 4	1,4	1,0	0,8
Net Energy Use Reduction	%	-5	0	-35	-61
Net Zero Energy for Single Family With PV	kWh/m²/year	< 45	61,8	41,3	31,8

Table 32: KPIs compliance for use case 3.

4.11.1 Energy Consumption KPI

The simulation results were evaluated against the project performance targets defined for use Case 3. The assessment considered three scenarios: the baseline condition, the renovated envelope scenario, and the renovated envelope combined with efficient use of the building.

As shown in Table 33, the baseline building presented an annual energy consumption of 79.7 kWh/m²·year, which was above the project target of < 50 kWh/m²·year. The renovation of the building envelope reduced the annual energy consumption to 59.2 kWh/m²·year, representing a significant improvement, although the target was not yet fully achieved. When the renovated envelope was combined with efficient use strategies, the energy consumption decreased further to 49.6 kWh/m²·year. Therefore, the Energy Consumption KPI was achieved in the renovated envelope + efficient use scenario.

4.11.2 Carbon Emissions KPI

Regarding carbon emissions, the project target was set at < 4 $kgCO_2/m^2$·year. Due to the very low carbon intensity of the Norwegian electricity mix, assumed as 0.017 $kgCO_2/kWh$ [9], the building already complied with this KPI in the baseline condition, with emissions equal to 1.4 $kgCO_2/m^2$·year. Nevertheless, the renovation measures further improved the result, reducing emissions to 1.0 $kgCO_2/m^2$·year in the renovated envelope scenario and to 0.8 $kgCO_2/m^2$·year when efficient use was also considered. This confirms that the proposed renovation strategy contributes to an additional reduction of operational carbon emissions, even in a context where the electricity supply is already highly decarbonised.

4.11.3 Net Energy Use Reduction KPI

The Net Energy Use Reduction KPI was also achieved. Compared with the baseline scenario, the renovated envelope scenario resulted in a 35% reduction in net energy use, while the combination of renovated envelope and efficient use achieved a 61% reduction. Both values are well above the project target of 5% reduction, demonstrating the effectiveness of the proposed renovation measures and the importance of operational behaviour in the overall performance of the building.

4.11.4 Net-Zero Energy Target

The Net Zero Energy for Single Family with PV KPI was assessed by considering the contribution of the BIPV system and assuming full utilisation of the generated electricity. In the baseline scenario, the resulting value was 61.8 kWh/m²·year, which was above the target of < 45 kWh/m²·year. With the renovated envelope, the value decreased to 41.3 kWh/m²·year, already complying with the target. In the renovated envelope + efficient use scenario, the value was further reduced to 31.8 kWh/m²·year, significantly below the project threshold.

4.11.5 Conclusions

Overall, use Case 3 demonstrates the effectiveness of combining bio-based renovation materials with renewable energy integration in cold-climate residential buildings. The application of mycelium-based insulation panels, wood fibre insulation and high-performance windows led to a substantial improvement in the building energy performance, reducing net energy use by 35% compared with the baseline. When efficient use strategies were also included, the reduction reached 61%.

The integration of BIPV further improved the operational performance of the building, allowing the net energy target for a single-family house with PV to be achieved in both renovated scenarios. The results therefore validate the potential of the proposed renovation solutions to support deep energy renovation objectives and contribute to low-carbon residential building transformation in Nordic climatic conditions.

5. Conclusions

This deliverable presents the energy modelling and simulation work carried out for the three EASI ZERo use cases, with the objective of assessing the impact of selected renovation strategies and EZ0 solutions on building energy performance, operational CO_2 emissions and project KPIs.

For the three demonstration buildings, baseline energy models were developed using IESVE. Depending on the available data, different modelling approaches were applied: sensitivity analyses were carried out for use Case 1 and use Case 2 to address input uncertainties, while use Case 3 benefited from a calibrated model based on monitored data.

The results demonstrate that the proposed renovation strategies lead to significant energy savings across different building typologies and climatic contexts. The results also show that passive envelope measures are essential to reduce heating demand, but that the combination with efficient systems and renewable energy production is necessary to reach the most ambitious KPI targets.

The study also highlights that some KPI targets, especially those related to carbon emissions or net zero energy performance, remain challenging to achieve in certain cases without further system decarbonisation or additional renewable energy production.

In conclusion, this study shows that EZ0 solutions can be adapted to different types of buildings, including residential, office and single-family houses, as well as buildings with specific constraints such as heritage or historical protection requirements. This confirms the flexibility and replication potential of the proposed solutions in a wide range of renovation contexts. However, the results also show that the effectiveness of these solutions depends on the initial condition of the building and its specific energy use profile, highlighting the need for complementary actions in some cases. For example, it may be more appropriate to first implement simpler and lower-cost measures, such as lighting upgrades when lighting represents a significant share of energy consumption, alongside the application of EZ0 renovation solutions.

6. References

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