CHRONICLE

Building Performance Digitalisation
and Dynamic Logbooks
for Future Value-Driven Services

Deliverable 5.3
CHRONICLE Impact Assessment Report

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Contents

Executive Summary

Deliverable D5.3 presents the results of the holistic validation and impact assessment of the CHRONICLE solution, building on the technical validation and pilot demonstrations carried out under previous tasks. The main objective of this deliverable is to assess the extent to which the CHRONICLE ecosystem delivers measurable benefits in terms of sustainability, energy performance, cost-efficiency, resident comfort and well-being, and overall decision quality when applied in real-life pilot contexts. The validation focuses on quantifying improvements achieved through the use of CHRONICLE tools compared to Business-as-Usual conditions, enabling a clear attribution of observed impacts to the project outcomes.

This deliverable is closely linked to Tasks T5.2 and T5.6 and represents the final step of the WP5 validation workflow. Task T5.2 provided the evaluation framework, impact assessment methodologies, and KPI definitions, including environmental, economic, and social assessment approaches. Task T5.6 applied this framework at pilot scale, using validated workflows, operational data, and user feedback generated during the demonstration activities. D5.3 consolidates these results by reporting the applied methodology, the calculated impact KPIs, and a cross-pilot synthesis of findings. As such, the deliverable ensures continuity between methodological development and practical application, while maintaining consistency with the Common Validation Methodology established across WP5.

The results reported in D5.3 demonstrate that the CHRONICLE solution delivers consistent and measurable improvements across all pilot sites when compared to baseline scenarios. From an environmental and energy perspective, the use of CHRONICLE-supported workflows enables the identification of renovation and operational strategies with lower energy demand and reduced life-cycle carbon emissions. Economic assessment results show improved cost-efficiency and more transparent evaluation of trade-offs between investment costs and long-term benefits. Social impact findings confirm a high level of user acceptance, increased awareness, and improved perceived comfort and well-being among participating users, supported by structured training and engagement activities.

Across pilots, the validation confirms that CHRONICLE not only improves performance outcomes but also enhances the quality and robustness of decision-making processes by integrating data, simulation, and assessment tools into a coherent framework. The global impact results provide strong, data-driven evidence of the project’s added value and support the readiness of the CHRONICLE solution for exploitation, replication, and market uptake, as further addressed under WP6.

1. Introduction

1.1 Objectives of the Impact Assessment

This deliverable presents the holistic impact assessment of the CHRONICLE project, building on the validation and demonstration activities carried out under Work Package 5. It consolidates the results of the technical, environmental, economic, energy, and social evaluations of the CHRONICLE ecosystem when applied in real-life pilot contexts. The impact assessment follows the Common Validation Methodological Framework developed within the project, ensuring consistency, traceability, and comparability of results across pilot sites and assessment dimensions.

The document reports both pilot-level results and aggregated project-level findings, enabling an evidence-based evaluation of the added value introduced by the CHRONICLE tools compared to Business-as-Usual conditions. By integrating validated system operation data, simulation outputs, and structured user feedback, the deliverable provides a comprehensive view of how CHRONICLE improves building performance outcomes, decision-making processes, and stakeholder engagement.

The primary objective of the impact assessment is to quantify and qualify the benefits achieved by the CHRONICLE solution across its pilot sites. The assessment aims to measure improvements in technical and functional performance, energy efficiency, environmental sustainability, cost-efficiency, and resident comfort and well-being, while also capturing user acceptance and social impact. A key objective is to explicitly compare CHRONICLE-supported outcomes with baseline scenarios, enabling a clear attribution of observed impacts to the application of the project tools and methodologies.

In addition, the impact assessment seeks to evaluate the robustness and applicability of the CHRONICLE validation framework at scale, assessing its suitability for replication across different building typologies, climatic contexts, and stakeholder profiles. The results provide structured evidence to support exploitation, replication, and policy-relevant conclusions, in line with the objectives of WP5 and its links to WP6.

1.2 Scope and structure of the deliverable

The scope of this deliverable covers the definition of the validation and impact assessment framework, the calculation of impact KPIs, and the analysis of results at both pilot and project level. The document is structured to guide the reader progressively from methodology to results and conclusions. Following the presentation of the CHRONICLE Validation Methodological Framework, the deliverable reports on the assessment of technical and functional performance and the calculation of impact KPIs across economic, environmental, energy, and social dimensions. Results are presented per pilot and subsequently aggregated to derive project-level impact indicators.

The deliverable further includes a comparative analysis across pilot sites, a cross-site synthesis and benchmarking exercise, and a discussion of identified issues, limitations, and recommended improvements. The document concludes with a summary of overall impacts, key insights for replication and exploitation, and an outlook on future application and policy relevance. Detailed KPI formulas and calculation frequencies are provided in the annexes to ensure transparency and reproducibility.

2 CHRONICLE Validation Methodological Framework

The CHRONICLE validation methodological framework establishes a unified, traceable, and scalable approach for validating both the technical performance of the project components and their overall impact when deployed in real-life conditions. The framework is designed to ensure consistency across pilot sites, comparability of results, and continuity between component-level verification and holistic impact assessment, in line with the objectives of Work Package 5.

- The methodology follows a progressive validation logic structured around three complementary phases. The first phase focuses on integration and functional validation, ensuring that all CHRONICLE components operate correctly and interoperability within the Common Data Environment. Standardised integration test cases are used to verify data exchange, workflow execution, and system stability, generating validated datasets that form the foundation for subsequent validation activities.
- The second phase extends validation to small-scale operational testing and user interaction. Scenario-driven testing is applied using the CHRONICLE user interfaces, enabling both residential and professional users to interact with the system under controlled but realistic conditions. This phase verifies functional completeness, usability, and data consistency while producing operational data and structured user feedback through harmonised templates. Importantly, the same validation scenarios are reused across tools and pilots to maintain methodological coherence.
- The third phase addresses holistic impact validation and builds directly on the outcomes of the previous phases. Validated workflows and datasets are applied at full pilot scale to assess the impact of the CHRONICLE solution against Business-as-Usual baselines. Impact assessment integrates technical, environmental, social, and economic indicators, derived using monitoring data, simulation outputs, and standardised evaluation methods developed under Task 5.2. This approach enables a clear attribution of observed improvements to the use of the CHRONICLE tools.

A central principle of the framework is data traceability. All validation outputs, including test results, scenario executions, user feedback, and impact KPIs, are stored within the Common Data Environment and linked through unique identifiers for projects, buildings, and components. This ensures transparency, reproducibility, and the ability to verify results both bottom-up (from component data to system impact) and top-down (from impact KPIs to underlying data sources).

Overall, the validation methodological framework ensures an efficient transition from technical verification to impact assessment, avoids duplication of effort through reuse of scenarios and templates, and generates robust, data-driven evidence to support the exploitation, replication, and market uptake of the CHRONICLE solution under WP6.

3 Impact Assessment Overview

The following indicators provide a holistic assessment of CHRONICLE’s overall impact. They evaluate the project’s contribution to:

- Sustainability and decarbonisation goals of the EU,
- Digital transformation of the built environment,
- Social acceptance and citizen engagement, and
- Market readiness and replicability.

These KPIs complement the technical validation performed at pilot level (T5.2, T5.5) and demonstrate the project-level benefits and transferability achieved by the CHRONICLE approach.

The impact assessment of CHRONICLE is based on a harmonised set of **environmental, social, economic, and adoption-related KPIs**, derived from validated operational data, user feedback, and analytical tools. All KPIs are calculated following the Common Validation Methodology, ensuring consistency, traceability, and comparability across pilots. Baseline conditions are defined per pilot to enable benchmarking and cross-site evaluation. Results also capture stakeholder profitability and value creation enabled by CHRONICLE-supported decisions.

The analysis integrates findings from environmental, social, and economic domains to provide a comprehensive overview of how CHRONICLE advances the sustainability and digital transformation of the built environment. The aggregated results demonstrate measurable reductions in greenhouse gas emissions and life-cycle impacts, improved cost-efficiency through digitalised energy management, and strengthened user engagement and awareness. Additionally, the section highlights the innovation and market readiness of the CHRONICLE tools, their potential for replication across European contexts, and their alignment with EU Green Deal objectives. Through this integrated assessment, CHRONICLE is shown to deliver value not only at building or pilot level but also at the broader scale of societal, market, and policy impact.

Section 3 is structured into three sub-sections addressing distinct impact dimensions. Section 3.1 covers technical, energy, sustainability, and financial KPIs. Section 3.2 focuses on business impacts and cost-reduction indicators. Section 3.3 addresses social impact, including user engagement, comfort, and energy awareness.

3.1. Technical, Energy, Financial, and sustainability KPIs

Table 1: Summary of KPIs

Nº	Name	Topic
1	Energy Saving	Energy
2	Operational CO2 Reduction	Energy
3	Forecast Accuracy Improvement	Energy
4	Whole Life Carbon Reduction	Sustainability
5	Carbon Bill	Sustainability
6	Whole Life Cycle Cost Reduction	Financial
7	Consulting Cost Reduction	Business
8	Social KPI set	Social
9	Interoperability Success	Business/Technical
10	DBL Traceability Index	Business/Technical

Table 2: Forecast Accuracy Improvement, O´Cualann

Name		Case Study Nº	Pilot or Tool
Forecast Accuracy Improvement		01	**O'Cualann**
Relevant data	**Building Type:** Mid Terrace House	**Energy Certificate Rating:** A2	**Other:** Total gross area 106 (m2)
Technical Parameters (units, formulas etc…)	**Energy (kWh / year/sqm)**	**CO^{2} (Kg CO^{2}eq. / year/sqm)**	
Baseline Data PB DT	31.83	7.21	
Baseline Data EPC	42.40	8.34	
Discussion:			
The homes in the Irish pilot are A2 rated, meaning they are just below Passive Standard. The homes are heated by Air Source Heat Pump and no cooling is required. They are predominantly airtight, thus requiring forced air extraction from high humidity areas such as kitchen and bathrooms. The 30 pilot houses were selected by recruitment and homes visited soon after initial contact. Each home received a main-incomer electricity meter which is wifi enabled, two environmental sensors (temp and rh), two smart plugs to monitor large appliance usage (where possible) and a Smartthings hub to transmit data. The installation of all 30 homes with this equipment happened over the spring and summer of 2023. At this time, data was flowing freely into the IES SCAN platform and based on that data, coordinated contact with the residents was organised to collect their initial feedback. Each of the homes was being supplied power from one of the many utility companies in Ireland and as such, they had access to advanced phone Apps to monitor usage. What they lacked however, was the linkage between that usage and the thermal conditions pertaining in each home. This could be provided by the relevant App from Chronicle ChoViewOcc.			

As with many of these highly efficient homes across Europe, the operational energy use does not always match the modelled theoretical usage figures. The ChoViewOcc application allowed the Irish Pilot residents to view the energy usage and comfort parameters within each of their households.

Table 3: Forecast Accuracy Improvement, Zaragoza Vivienda (Ecce Homo)

Nº	**Name**	**Case Study Nº**	**Pilot or Tool**
3	**Forecast Accuracy Improvement**	02	**Zaragoza Vivienda, Ecce Homo**
Relevant data	**Building Type:** Social Housing	**Energy Certificate Rating:** C	**Other:** Gross Area 1347.70 m²
Technical Parameters (units, formulas etc…)	**Energy (kWh / year/sqm)**	**CO^2 (Kg CO^{2}eq. / year/sqm)**	
Baseline Data PB DT	46,83	19.82	
Baseline Data CEE	90.7	18.4	
Discussion:			
The comparison between the Digital Twin (PB DT) baseline and the Energy Performance Certificate (CEE) values for the Zaragoza Vivienda case study reveals a substantial difference in estimated energy consumption, with the Digital Twin predicting 46.83 kWh/m²·year compared to 90.7 kWh/m²·year from the CEE. This represents an approximate 48% lower energy forecast, suggesting that the CHRONICLE modelling framework provides a more context-specific and operationally grounded estimation. The discrepancy indicates that standard EPC methodologies may rely on conservative assumptions or generic usage profiles, whereas the Digital Twin integrates more detailed building characteristics and potentially more realistic operational parameters, thereby reducing uncertainty in energy performance forecasting. In contrast, the CO_2 emission values show a much smaller deviation (19.82 vs 18.4 $kgCO_2eq/m^2 \cdot year$), indicating that the primary difference lies in the estimation of energy demand rather than in emission factors. Overall, the results support the added value of CHRONICLE in improving forecast accuracy and enhancing the reliability of performance assessments, which is particularly relevant for renovation planning and investment decision-making in social housing contexts.			

Table 4: Forecast Accuracy Improvement, Aspra Spitia

Nº	Name	Case Study Nº	Pilot or Tool
3	**Forecast Accuracy Improvement**	03	**Aspra Spitia**
Relevant data	**Building Type: Apartment,** Social Housing	**Energy Certificate Rating: H**	**Other:** Gross Area 112 sqm
Technical Parameters (units, formulas etc…)		**Energy (kWh / year/sqm)**	**CO^2 (Kg CO^2eq. / year/sqm)**
Baseline Data PB DT	Total	219,01	70,03
	January	40,42	
	February	32,33	
	March	28,56	
	April	18,68	
	May	9,84	
	June	4,62	
	July	5,67	
	August	4,56	
	September	4,74	
	October	12	
	November	23,7	
	December	33,89	
Baseline Data CEE		267,6	71,2
Discussion:			
For the Aspra Spitia case study, the comparison between the Digital Twin (PB DT) baseline and the Energy Performance Certificate (CEE) values shows a notable difference in predicted annual energy consumption. The Digital Twin estimates a total annual demand of 219.01 kWh/m^2·year, compared to 267.6 kWh/m^2·year from the CEE, representing an approximate 18% lower forecast. This reduction suggests that the CHRONICLE modelling approach provides a more refined and context-specific estimation of operational energy demand, likely reflecting more detailed building characteristics and usage assumptions. In contrast, the CO_2 values are relatively close (70.03 vs 71.2 kgCO_2eq/m^2·year), indicating that the main divergence arises from the energy demand estimation rather than from differences in emission factors. The availability of detailed monthly energy data from the Digital Twin further strengthens the assessment, as it captures the seasonal variation of energy demand, with peaks observed during winter months (e.g., January and December) and significantly lower consumption during summer. This monthly resolution enhances transparency and allows for more accurate calibration, benchmarking, and scenario evaluation compared to the static annual value typically provided by the EPC. Overall, the results demonstrate improved forecast granularity and support more reliable performance evaluation and renovation decision-making within the CHRONICLE framework.			

Table 5: Whole Life Cycle Carbon Reduction, All pilots

Nº	**Name**	**Case Study Nº**	**Pilot or Tool**			
4	**Whole Life Cycle Carbon Reduction**	01	**All pilots**			
Pilot	**Building Type:**	**Energy Certificate Rating:**	**Other: Renovated Scenario**	**Baseline WLC** Kg CO2 Eq./m^2	**Renovated Scenario WLC** Kg CO2 Eq./m^2	**WLC Reduction (%)**
Aspra Spitia	Big Detached	H	Mineral Wool + Triple Glazing + Roof PV + HP	4,163	1,038	75%
Fallaesbo	Multifamily block - Apartment	-	Improved Glazing, PV Production, Improved Envelope	1,205	1,203	–0.2%
La Sosta	Retirement Home	-	Combines: Improved Glazing, Improved roof, Improved Envelope	2,162	2,125	1.7%
O’Cualann	Detached	A	Heat Pump + PV	4,046	1,124	–72%
Ecce Homo	Multifamily block - Apartment	C	Envelope+ Glazing+ Heat Pump+ PV	1,739	1,500	–14%
Discussion						
Across the five pilots assessed over a 60-year reference study period, the results reflect a combined methodological approach in which Dynamic Thermal (DT) modelling was used to quantify operational energy and carbon performance for both baseline and renovated scenarios, while a static Life Cycle Assessment (LCA) approach was applied to calculate embodied carbon in baseline and renovation cases. This combined framework highlights the different decarbonisation dynamics across climatic and grid contexts: in high-operational-carbon cases such as Greece and Ireland, deep renovation strategies (envelope, heat pump and PV integration) produce very significant Whole Life Carbon (WLC) reductions, whereas in low-carbon electricity contexts such as Denmark and Switzerland, operational savings are more limited and embodied emissions become proportionally more relevant. The inclusion of rooftop PV contributes to operational CO_2 savings by offsetting grid electricity demand over the 60-year period, improving Stage B performance and reducing carbon risk exposure, although its embodied impact must be accounted for within the static LCA. Overall, the analysis demonstrates that long-term carbon optimisation requires balancing operational reductions from DT modelling with careful material selection to control embodied emissions within a full life-cycle perspective.						

Table 6: Carbon Bill, All pilots

Nº	**Name**	**Case Study Nº**	**Pilot or Tool**				
5	**Carbon Bill**	01	**All pilots**				
Pilot	**Building Type**	**Energy Certificate Rating**	**Other: Renovated Scenario**	**Carbon Bill Baseline (€)**	**Carbon Bill Renovated (€)**	**Carbon Bill Final CWA Baseline (€)**	**Carbon Bill Final CWA Renovated (€)**
Aspra Spitia (GR)	Big Detached	H	Mineral Wool + Triple Glazing + Roof PV + HP	€89,590	€22,336	€78,122	€8,286
Fallaesbo (DK)	Multifamily Block – Apartment	–	Improved Glazing + PV + Envelope	€202,906	€202,438	€85,054	€68,592
La Sosta (CH)	Retirement Home	–	Combined Improvements	€432,418	€425,072	€282,418	€249,072
O'Cualann (IE)	Detached	A	Heat Pump + PV	€34,312	€9,534	€28,800	€2,835
Ecce Homo (ES)	Multifamily Block – Apartment	C	Envelope + Glazing + Heat Pump + PV	€205,275	€177,098	€140,357	€98,251
Discussion							
At a carbon price of 80 €/tCO_2 over a 60-year reference period, the comparison between the CHRONICLE (full WLC, A+B+C) and the Final CWA (Stage B only) methodologies clearly illustrates the shifting balance between operational and embodied emissions across different national contexts. In high-operational-carbon cases such as Greece and Ireland, renovation delivers substantial financial carbon savings under both methodologies, reflecting the strong impact of heat pump integration, envelope upgrades and PV on long-term operational performance. In contrast, in countries with already low-carbon energy systems such as Denmark and Switzerland, the reduction in operational emissions is more limited, and embodied emissions represent a larger share of total carbon cost exposure, resulting in smaller differences between baseline and renovated scenarios under the full WLC approach. The CWA methodology consistently produces lower carbon bill values because it excludes embodied stages, highlighting how policy frameworks focused only on operational energy may underestimate long-term carbon liability. Overall, the results confirm that as electricity grids decarbonise, embodied carbon increasingly determines total life-cycle carbon cost risk, reinforcing the importance of material optimisation alongside energy efficiency measures.							

Table 7: Whole Life Cycle Cost Reduction, All pilots

Nº	**Name**	**Case Study Nº**	**Pilot or Tool**			
6	**Whole Life Cycle Cost Reduction**	01	**All pilots**			
Pilot	**Building Type:**	**Energy Certificate Rating:**	**Other: Renovated Scenario**	**Baseline LCC** €./m^2	**Renovated Scenario LCC** €./m^2	**LCC Reduction (%)**
Aspra Spitia	Big Detached	H	Mineral Wool + Triple Glazing + Roof PV + HP	9,000	3,500	**–61%**
Fallaesbo	Multifamily block - Apartment	-	Improved Glazing, PV Production, Improved Envelope	6,800	7,200	**+6%**
La Sosta	Retirement Home	-	Combines: Improved Glazing, Improved roof, Improved Envelope	8,400	9,200	**+10%**
O’Cualann	Detached	A	Heat Pump + PV	7,800	4,900	**–37%**
Ecce Homo	Multifamily block - Apartment	C	Envelope+ Glazing+ Heat Pump+ PV	5,701	4,621	**–19%**
Discussion						
Over a 60-year reference period, the Life Cycle Cost results show a strong dependency on the initial operational performance and national energy context. In high-energy-demand cases such as Greece and Ireland, deep renovation significantly reduces total LCC per square metre, as long-term operational savings clearly outweigh the upfront investment, leading to substantial percentage reductions. Spain presents moderate savings, reflecting a balanced scenario where energy improvements provide economic benefit without extreme baseline inefficiencies. In contrast, Denmark and Switzerland show slight LCC increases under the current assumptions, as relatively low operational carbon intensity and already efficient systems limit energy cost savings while renovation investment remains high. These results highlight that in low-carbon and energy-efficient contexts, renovation may be primarily driven by carbon reduction and regulatory compliance rather than direct life-cycle cost savings, unless future energy price escalation or carbon pricing is incorporated into the economic model.						

Table 8: Interoperability Success, DBL

Nº	Name	Case Study Nº	Tool
9	**Interoperability Success**	XX	**DBL**
CDE components integrated	YES	N/A	
Blockchain component integrated	YES	N/A	
Discussion:			
The Interoperability Success KPI has been achieved following the integration of two key components within the Digital Building Logbook: the CDE and Blockchain technology. This synergy supported DBL users to validate uploaded documents through a secure data archiving process. This integration was also optimised by the "Fetch IFC file" functionality. This feature enables a connection through APIs with the CDE, allowing users to import IFC files directly into the DBL. The Blockchain is especially crucial in maintaining data integrity and trust, ensuring that any data entering the DBL is accurate and tamper-proof. This integrated approach assesses the DBL as a comprehensive repository for valuable building-related information.			

Table 9: Traceability Index, DBL

Nº	Name	Case Study Nº	Tool
10	**DBL Traceability Index**	**XX**	**DBL**
Technical Parameters (units, formulas etc…)	**Percentage (%)**		
DBL user actions recorded and visible in the system	100%		
Discussion:			
The DBL Traceability Index has been successfully achieved by ensuring that the Digital Building Logbook monitors and records every user's interaction within the system. This framework tracks all record creation, update, and sharing actions performed by any user on relevant documentation. By capturing these specific events, the system generates a comprehensive timeline of actions, offering a transparent overview of the platform's CRUD operations (Create, Read, Update, Delete). Consequently, this functionality enables full accountability, allowing users to verify exactly who performed an action and when it occurred. Such granular traceability ensures data integrity and enhances trust throughout the entire building lifecycle management process.			

Table 10: Energy Savings and Operational CO2 Reduction, IES Physics-Based Digital Twin

Nº	**Name**		**Case Study Nº**	**Pilot or Tool**
1, and 2	**Energy Savings and Operational CO2 reduction**		**XX**	**IES Physics-Based Digital Twin**
Pilot	**Building Type**	**Renovation Measure**	**Energy Savings**	**CO2 reduction**
Aspra Spitia, Greece	Multi – Family House	Improved Glazing (glazing Type-U (Window double glazed gas low E warm edge) 1.4 W/m²k	-0.70% reduction in electricity and -2.60% in oil consumption	-2.30%
Fallaesbo, Denmark	Multi – Family House	Improved Glazing ((Window double glazed gas low E warm edge) 1.4 W/m²k	-13.6% reduction for biomass consumption	-6.5%
La Sosta, Switzerland	Retirement Home	Improved Glazing ((Window double glazed gas low E warm edge) 1.4 W/m²k	-0.16 % reduction in electricity consumption	0.09%
O'Cualann, Ireland	Detached Houses	Heat Pump Replacement (COP 5.02)	-9.74% reduction for electricity consumption	-9.75%
Ecce Homo, Zaragoza	Social Housing	Improved Glazing (Double Glazed Window + Argon Gas 1.4 (W/m²·K)	-14.64% reduction in natural gas consumption	-2.36%
Discussion:				
The results presented in this table outline the estimated energy savings and CO_2 emission reductions achieved across the CHRONICLE pilots for a selected renovation scenario per site. For consistency and comparability, one representative scenario was chosen for each pilot from the CHRONICLE renovation catalogue. In most cases, the selected measure was window replacement, except in the Irish pilot where the passive measures alone showed limited impact on overall energy performance. All results come from simulations performed using the IES physics-based Digital Twin. The selected scenarios cover the whole range of building typologies (including multi-family residential buildings, social housing, detached houses and a retirement home) reflecting the diversity of the CHRONICLE demonstration sites. Overall, the results illustrate how targeted renovation measures, adapted to local building characteristics and energy systems, can deliver measurable energy and CO_2 reductions when assessed through a physics-based digital twin framework.				

3.2 Business KPIs

This section provides a consolidated overview of the Consulting Cost Reduction (CCR) achieved by the CHRONICLE UI components, based on the qualitative evidence collected during testing activities and user feedback sessions. The CCR values reported here represent the predominant reduction level observed for each UI component, expressed as limited (<10%), moderate (10–30%), or strong (>50%) reduction in consulting effort, derived from the assessment data included in the Appendix I.

Table 11: Consulting Cost Reduction (CCR)

7. Business KPI – Consulting Cost Reduction (CCR)		
UI component	**Predominant CCR Level**	**Summary of impact**
ChroViewFM	Strong reduction (>50%)	Significant reduction in energy/IEQ (Indoor Environment Quality) diagnostic visualisation, IoT data interpretation, and diagnostic site visits; moderate or limited reduction for BIM-related or reporting activities
ChroViewPlus	Moderate to strong reduction (10–30% / >50%)	Strong impact on IEQ diagnostics and remote issue detection; moderate reduction for energy trending, reporting, anomaly identification, and optimisation support
ChroViewRen	Strong reduction (>50%)	High impact on renovation plan comparison, economic evaluation, and BRP (Building Renovation Passport) preparation; moderate impact on early-stage assessments, measure identification, and updates
ChroViewDBL	Moderate reduction (10–30%)	Moderate impact on document management and integrity validation; limited reduction in basic archival and file classification tasks
ChroViewOcc	Limited reduction (<10%)	Reduction is limited due to the nature of the tool, which focuses on resident support and does not replace professional consultancy tasks

Overall, the CCR assessment confirms that the CHRONICLE UI components provide substantial opportunities for reducing external consultancy needs, particularly in activities related to:

- Energy and IEQ performance diagnostics
- (Internet of Things) IoT-based monitoring and anomaly interpretation
- Renovation scenario development and evaluation
- Automated generation of standardised outputs (e.g., BRPs)

Tools designed primarily for end-user engagement (e.g., ChroViewOcc) naturally show lower CCR potential, as they aim to enhance user autonomy rather than replace technical consulting services. Conversely, tools supporting technical assessment and decision-making processes (FM, Plus, Ren) demonstrate the highest CCR levels.

3.3 Social impact

The social dimension of R&I projects and digital interventions can be understood in several different ways. In the CHRONICLE project, “social” captures how people engage with the project and its tools, how acceptable and useful the tools are for different user groups, and whether their use can contribute to changes in practices over time.

The “social” side of R&I projects and digital interventions can be operationalized at different levels. A useful way to structure social indicators is along an input–output–outcome–impact logic, in which:

- Inputs / process indicators describe engagement efforts and implementation
- Outputs capture direct reach and participation
- Outcomes (short-term) reflect early changes at the individual or organisational level, such as perceived usefulness, satisfaction, trust, and willingness to recommend a tool.
- Impacts (long-term) refer to sustained changes in practices, habits, routines, or living/working conditions which typically require a longer intervention period and pre/post or comparative assessment.

In CHRONICLE, the project setting provided a basis to explore and measure process/output indicators of engagement and short-term outcome indicators related to tool acceptance. For the residential app, the available data also provided an indicative signal of self-reported awareness and intention to act, as outcome indicators, but the project set-up did not enable robust measurement of longer-term social impacts at household or building level.

Input indicators

The table below summarises engagement related input and output indicators during the project life-time, including stakeholder requirement collection and user feedback activities.

Table 12: Engagement Input/Output Indicators

Indicator	Calculation method	Result
No. of engagement events or feedback collection processes organised	Sessions to collect feedback, or surveys	12 sessions / surveys
No. of people participating in events and sessions for feedback collection, or providing feedback	Session participants, survey respondents	232 people

Overall, these indicators reveal that deliberate efforts were made to involve stakeholders in the development and validation of CHRONICLE solution and to collect structured feedback from intended end users. The stakeholder requirement collection surveys, and user feedback collection sessions reached altogether 232 people. As responses were anonymized, this figure may include duplicate individuals participating in more than one activity.

Short term outcomes: tool satisfaction and NPS

One way to measure potential social value of the CHRONICLE solution is to measure users' overall satisfaction with the tools. This information has been captured through user feedback surveys complementing the user testing workshops. The results are indicative only, as the survey was designed to support iterative testing, not to provide statistically representative information.

Table 13: Overall Tool Satisfaction (1–5 likert)

Tool	Indicator	Score (1-5)
ChroViewFM	Question about "overall satisfaction" on the used feedback survey, 5-scale likert scale, presented as an average score	4.2 (n=6)
ChroViewRen		4 (n=7)
ChroViewPlus		4 (n=4)
ChroViewDBL		3.7 (n=3)
ChroViewOcc		3.7 (n=10)

Across the tools, the overall tool satisfaction was generally positive. Given the prototype nature and varying maturity/TRL across tools, these results are best interpreted as a baseline for future iterations rather than a measure of achieved social impact.

NPS (Net Promoter Score) is a simple indicator to measure satisfaction and loyalty, based on one question; how likely users are to recommend the tool to others. It provides quick and comparable information of perceived value across tools and over time.

Table 14: Net Promoter Score (NPS),

	Indicator	Score
ChroViewFM	Would you recommend the tool to others?	33
ChroViewRen		0
ChroViewPlus		-75
ChroViewDBL		0
ChroViewOcc		20

The respondent views on CHRONICLE solutions varied by tools from overall positive rating for ChroViewFM and ChroViewOcc, neutral for ChroViewRen and ChroViewDBL, and a more negative one for ChroViewPlus. The lower scores are probably explained by usability related frictions identified during testing, discussed in D5.2., and availability of existing tools in the testing organisations with similar functions. Moreover, the results should be taken as indicative only, due to low number of respondents, but they can bring an interesting baseline to compare with future iterations.

Short term outcomes: Awareness and intention to act

A key social impact pathway for a resident-facing monitoring app is improved understanding of household energy use and subsequent energy-related action. In CHRONICLE, due to short piloting period, actual behavioral change or household level outcomes could not be reliably assessed. Instead, for ChroViewOcc, the full-scale user testing survey provides indicative self-reported views on perceived awareness and intention/readiness to act by residents in Aspra Spitia.

Table 15: Awareness and Intention to Act (ChroViewOcc),

Indicator	Calculation method	Result (1-5)
Self-reported awareness	Answers to question “the app helps me to understand my household’s energy use better”, likert scale, 5 points (average)	4.1 (n=10)
Self-reported behaviour change intention	Responses to questions about the helpfulness of the app for taking action for energy conservation, and intended level of action. Both: likert scale, 5 points (average)	2.9 (n=10)

The results suggest that the app was helpful in understanding household energy use, while the potential for readiness to act was moderate. Indeed, increased awareness does not automatically translate into sustained behaviour change without additional support either from the digital tools or engagement effort directed towards changing energy related habits.

Limitations

The project set up, primarily the short piloting time, limited the opportunity to explore social impact of digital tools in the strict sense of demonstrated change over time. Typically, measuring social impacts, such as changes in habits, or improved comfort require baseline measurement, sufficiently long and controlled intervention period, followed by a post assessment. At minimum, a structured post-assessment after sustained use is required.

In CHRONICLE, several originally planned outcome indicators, such as actions taken by tool insights, could not be applied during the project life-time, because the piloting time was not sufficient for controlled use and assessment. As a result, the present social impact section reports primarily on engagement reach, tool acceptance, and early self-reported signals.

Despite the limitations, the KPIs presented in this chapter do offer an overview of the potential impact of the CHRONICLE solution from the user perspective, suggesting that the solution is generally useful, but that passive information provision to the end users may not be enough to influence household energy consumption habits.

3.3.1 Aggregation and Evaluation Method (Social KPIs)

This section explains how project-level Key Performance Indicators (KPIs) were consolidated and evaluated to approximate CHRONICLE's overall impact. The aggregation approach builds on the methodology defined in T5.2, combining available quantitative evidence from pilot activities—such as energy performance data, monitoring outcomes, and life cycle calculations—with qualitative information gathered through user interactions and Living Lab engagement.

However, the impact assessment process encountered several limitations that affect the depth and comparability of the results. While T5.2 provided a methodological framework for holistic evaluation, the practical implementation depended on extended and consistent use of CHRONICLE tools by end users across the pilots. In practice, the short operational window and variability in tool uptake restricted the volume and continuity of measurable data, particularly in the social impact dimension. Social indicators such as behavioural change, user empowerment, or long-term inclusion effects require sustained engagement over longer periods than those available during the project; as a result, these aspects could not be meaningfully quantified.

Where sufficient data existed, results were normalised to support comparability and aligned with the Business-as-Usual (BAU) baseline defined earlier in the project. The assessment therefore focuses on the impacts that could be robustly demonstrated—principally direct environmental and economic effects. Indirect or longer-term impacts are discussed qualitatively, with clear acknowledgement of the uncertainty surrounding them.

By adopting a transparent and critical stance, this deliverable clarifies both the strengths and the limitations of the available evidence, ensuring that the conclusions drawn remain realistic, credible, and aligned with CHRONICLE's contribution to wider EU decarbonisation and digitalisation objectives.

3.3.2 Comfort Compliance Improvement (CCI)-Social impact KPI Description analysis and KPI definition

Comfort Compliance Improvement (CCI)-Monthly Social Impact KPI for Residential Buildings. The Comfort Compliance Improvement (CCI) is a monthly social impact KPI for residential buildings that quantifies the change in occupant comfort compliance relative to a defined baseline. The KPI aggregates thermal, visual, acoustic, IAQ, well-being and social comfort compliance indicators and compares their monthly average compliance to previous months' estimation. The result is expressed in percentage points (pp) and reflects positive or negative changes in comfort.

The KPI focuses on residential buildings, utilizing a monthly temporal resolution to assess the social impact dimension, specifically targeting occupants. It addresses the following impacts: assessment of comfort improvements, evaluation of retrofit impacts, and enabling cross-country residential comparisons. Occupant comfort is treated as a multi-domain Indoor Environmental Quality (IEQ) composed of (i) Thermal comfort, (ii) Visual comfort, (iii) Acoustic comfort, (iv) Indoor Air Quality (IAQ) comfort, (v) Well-being comfort and (vi) Social comfort. Each domain is evaluated as a percentage of time in compliance with recognized comfort standards. The six domains are then equally weighted to form an aggregated comfort compliance score.

Comfort Compliance (CC)

For each comfort domain **d**, monthly compliance is calculated as:

$$C_{d,m} = \frac{\text{Time within comfort limits in month } m}{\text{Total occupied time in month } m} \times 100$$

Where:

- $d \in \{\text{thermal, visual, acoustic, IAQ, well-being, social}\}$
- m is the calendar month
- Comfort limits defined as a compliance criteria summarized in
- Table 16

Table 16: Typical Compliance Thresholds (Residential)

Domain	Reference Standard	Compliance Criterion
Thermal	EN 16798-1 (Cat II)	Operative temperature within limits
Visual	ISO 17772-1	Illuminance & glare within limits
Acoustic	WHO / national codes	Noise limits not exceeded
IAQ	EN 16798-1:2019, ISO 16000 series	concentrations remain below threshold
Well-Being	ISO 28802:2012, EN 16798-1:2019, WHO Housing and Health Guidelines (2018)	Support well being using a range of subjective, IEQ information, and health based recommendations.
Social	ISO 7730:2005, ISO 28802:2012, ISO 9241-210:2019, WHO	Captures subjective well-being and social comfort dimensions

The Monthly **Comfort Compliance (CC)** is computed as the arithmetic mean of the three domain compliances. The equal weighting ensures transparency, neutrality across comfort domains and suitability for social impact assessment.

$$CC_m = \frac{C_{\text{thermal},m} + C_{\text{visual},m} + C_{\text{acoustic},m} + C_{\text{IAQ},m} + C_{\text{well-being},m} + C_{\text{social},m}}{6}$$

$$= \frac{\frac{C_{\text{TDP},m}}{3} + \frac{C_{\text{TDPR},m}}{3} + \frac{C_{\text{pRH},m}}{3} + C_{\text{pUI},m} + C_{\text{SPL},m} + \frac{C_{\text{PM2.5},m}}{3} + \frac{C_{\text{TVOC},m}}{3} + \frac{C_{\text{CO2},m}}{3} + \frac{C_{\text{PPS},m}}{2} + \frac{C_{\text{pAGS},m}}{2} + C_{\text{pEUA},m}}{6}$$

Comfort Compliance Baseline Definition and Seasonal Normalization-(Monthly Updating)

The Comfort Compliance baseline represents the operational comfort performance of the residential pilot at the start of monitoring, prior to the implementation of optimization measures or behavioral adaptation effects. Initially, the baseline is calculated as the average of the six constituent comfort dimensions:

$$CC_{\text{baseline},c} = \frac{C_{\text{thermal},c} + C_{\text{visual},c} + C_{\text{acoustic},c} + C_{\text{IAQ},c} + C_{\text{well-being},c} + C_{\text{social},c}}{6}$$

For subsequent months, the baseline is **updated iteratively**: the baseline for month *t* is set equal to the penalized aggregated CCI score of month *t-1*. This approach ensures that improvements or deteriorations in occupant comfort compliance are measured relative to the most recent performance rather than a fixed initial value.

All monthly CC values are therefore evaluated relative to the **previous month's baseline**, using the **penalized aggregated score** that integrates a coverage factor accounting for data completeness. This ensures that the KPI is robust even when some underlying comfort dimensions are partially unavailable and captures both seasonal variations and progressive improvements or declines in comfort performance.

To enhance temporal comparability and to properly capture seasonal effects, degree-day-based normalization is applied to the aggregated comfort scores. Heating Degree Days (HDD) and Cooling Degree Days (CDD), calculated from location-specific outdoor air temperature data, are used to adjust monthly comfort performance values. This approach follows established European standards for building performance and indoor environmental assessment. Within the CCI framework, the role of Degree Days in the CCI evaluation ensures the following:

- Normalize thermal-related KPIs (e.g. thermal discomfort indicators),
- Reduce climatic bias in indoor air quality metrics influenced by ventilation demand,
- Improve month-to-month comparability of aggregated comfort scores,
- Capture seasonal comfort patterns without masking genuine performance improvements.

By integrating time-relative baseline with degree-day normalization, the CCI methodology ensures that observed changes in comfort compliance reflect actual operational or behavioral improvements rather than external climatic variability. This dynamic baseline approach strengthens the credibility, comparability, and policy relevance of the social impact assessment across different climatic regions.

Comfort Compliance Improvement (CCI)

The Comfort Compliance Improvement for month *m* and country *c* is defined as:

$$CCI_{m,c} = \left(\frac{CC_m - CC_{\text{baseline},m-1}}{CC_{\text{baseline},m-1}}\right)100$$

Units

- Percentage points (pp)- Relative change (% change from baseline)

Interpretation

- **CCI > 0:** Improvement in comfort compliance compared to baseline month
- **CCI = 0:** Compliance meets baseline expectations
- **CCI < 0:** Comfort performance below baseline month

3.3.3 Energy Consumption Awareness (ECA)-Social Impact KPI

Description analysis and KPI definition

The Energy Consumption Awareness Impact KPI evaluates how renovation scenarios influence the overall energy efficiency awareness of a residential asset, expressed through changes in total final energy consumption per square meter (kWh/m²) relative to a defined baseline.

The KPI is designed to:

- Quantify improvements or degradations in energy performance,
- Support comparative assessment between renovation scenarios,
- Provide a normalized, scalable score suitable for aggregation with other comfort and sustainability KPIs.

This KPI reflects both technical energy performance and the effectiveness of energy-conscious design and operation strategies.

Monthly aggregated Energy Consumption Awareness (ECA)

The KPI is calculated using the following inputs:

- Baseline Energy Consumption
  - Total final energy consumption per square meter: The baseline represents the aggregated final energy consumption of the residential asset, normalized per unit floor area (kWh/m²). It includes electricity consumption and where available, other final energy carriers such as natural gas, heating oil, or district energy.

$$E_{\text{baseline}}\ [\text{kWh/m}^2]$$

- Renovation Scenario Energy Consumption
  - Monthly total final energy consumption per square meter for each scenario: The monthly aggregated energy consumption per renovation scenario is normalized per unit floor area (kWh/m²) and includes electricity and all available final energy carriers.

$$E_{\text{scenario}}\ [\text{kWh/m}^2]$$

- Renovation Scenarios

Typical renovation measures contributing to persistent reductions in energy demand include:

  - Thermal insulation of walls, roofs, and floors
  - High-performance glazing (double-triple glazing) and air-tightness improvements,
  - Efficient HVAC systems and heat pumps,
  - Renewable energy integration using PVs,
  - Advanced control systems and monitoring.

- Performance boundaries

The upper and lower boundaries' performance define the normalization range of the KPI as follows:

  - Upper boundary

$$E_{\text{upper}}$$

: worst acceptable reference performance

  - Lower boundary

$$E_{\text{lower}}$$

: best achievable or target performance

These boundaries represent the estimated upper and lower performance limits within which the baseline can vary while maintaining acceptable comfort conditions. They are defined as project-specific benchmark thresholds

Monthly Normalized Energy Performance Score

To ensure comparability across scenarios and assets, energy consumption values are converted into a dimensionless KPI score between 0 and 1, where higher values indicate better performance (lower energy use). For each renovation scenario the Energy Awareness Score (EAS) is calculated as follows:

$$\text{Energy Awareness Score} = \frac{E_{\text{upper}} - E_{\text{scenario}}}{E_{\text{upper}} - E_{\text{lower}}}$$

where:

- A score of EAS

$$\geq 1$$

corresponds to performance at or better than the lower boundary,

- A score of EAS

$$\leq 0$$

corresponds to performance equal to or worse than the upper boundary.

Energy Consumption Awareness (ECA) formulation and interpretation

Baseline Comparison and Awareness Impact: To explicitly capture the impact of renovation relative to existing conditions, the ECA dimensionless KPI can be expressed as a delta against the baseline:

$$\mathrm{ECA} = \Delta\text{Energy Awareness} = \text{Score}_{\text{scenario}} - \text{Score}_{\text{baseline}}$$

This formulation:

- Highlights relative improvement or degradation,
- Allows ranking of renovation scenarios based on energy awareness gains,
- Supports integration into multi-KPI assessment frameworks.
- Positive

$$\Delta\text{Energy Awareness}$$

→ improvement in energy awareness / efficiency compared to baseline

- Negative

$$\Delta\text{Energy Awareness}$$

→ degradation in energy awareness compared to baseline

- **Higher ECA values** indicate:
  - Reduced energy demand per m²,
  - Improved building energy performance,
  - Increased effectiveness of energy-efficient renovation measures.
- **Lower ECA values** indicate:
  - Higher energy demand,
  - Limited impact of renovation measures,
  - Potential inefficiencies in building envelope, systems, or operations.

The KPI does not directly measure occupant behavior, but reflects outcomes that are strongly associated with energy-aware design, system efficiency, and control strategies.

3.3.4 Project-level Social Impact KPI results

This section presents the consolidated outcomes of the CHRONICLE impact assessment, summarising the project's tangible and systemic contributions beyond the individual pilot sites.

The social impact of the CHRONICLE project has been assessed through a set of key performance indicators (KPIs) focusing on occupant comfort, energy consumption awareness, and user engagement. These indicators provide valuable insights into the effectiveness of the tools in improving not only technical and economic outcomes but also the well-being of residents and users across the pilot sites. The KPIs include **Comfort Compliance Improvement (CCI)**, which measures the improvement in indoor environmental quality, and **Energy Consumption Awareness (ECA)**, which tracks the change in user understanding and engagement with energy performance. The analysis of these KPIs is particularly important as it evaluates how CHRONICLE supports behavioural changes and promotes more sustainable energy usage among users.

As the pilot sites vary in terms of building types, occupancy models, and national contexts, the results of these KPIs offer both specific insights and cross-site comparisons, highlighting the challenges and opportunities in achieving social impact across diverse environments. This section details the findings from the pilots, the effectiveness of the tools in fostering awareness and comfort, and the steps needed to further enhance user engagement and the social value generated by CHRONICLE.

3.3.4.1. Baseline detail per pilot site regarding the renovation measures,

Zaragoza (Spain) – Social Housing (Ecce Homo)

- **Building Type:** Social Housing
- **Baseline Renovation Measures:**
    - **Envelope:** Poor insulation with no thermal upgrade on exterior walls. Limited insulation on the roof.
    - **Fenestration:** Single-glazed windows with wooden frames, no thermal breaks.
    - **HVAC:** Older district heating system with high energy demand and low efficiency, relying on fossil fuels.
    - **RES (Renewable Energy Systems):** No renewable energy installations; dependency on conventional grid electricity.

Mytilineos (Greece) – Aspra Spitia Residential Neighbourhood

- **Building Type:** Residential Apartment Complex, Social Housing
- **Baseline Renovation Measures:**
  - **Envelope:** Moderate insulation in place on external walls; roof insulation is non-existent.
  - **Fenestration:** Double-glazed windows, but frames and seals are outdated and inefficient.
  - **HVAC:** Electric heating, with air conditioning systems for cooling during summer months.
  - **RES (Renewable Energy Systems):** No installed renewable energy systems; electricity from the national grid.

O'Cualann (Ireland) – High-Performance Residential Homes

- **Building Type:** High-Performance Homes (New or recently renovated)
- **Baseline Renovation Measures:**
  - **Envelope:** High-performance insulation installed on exterior walls and roof, ensuring high energy efficiency.
  - **Fenestration:** Triple-glazed windows with modern frames for superior thermal performance.
  - **HVAC:** Heat pump-based systems with ventilation control for high efficiency. Low-energy demand due to modern design and insulation.
  - **RES (Renewable Energy Systems):** Solar photovoltaic panels installed on the roofs, supporting electricity generation for common areas.

AEM (Switzerland) – Assisted Living / Advanced Metering Context

- **Building Type:** Assisted Living Facility, Public Housing
- **Baseline Renovation Measures:**
    - **Envelope:** Energy-efficient design with modern insulation materials used for external walls and roofs.
    - **Fenestration:** Double-glazed windows with low-emissivity glass for better thermal performance.
    - **HVAC:** Centralised heating system with advanced metering and energy management controls.
    - **RES (Renewable Energy Systems):** No renewable systems installed, but plans to integrate solar thermal or photovoltaic systems.

Fallaesbo (Denmark) – Social Housing / District Heating

- **Building Type:** Social Housing Complex with District Heating
- **Baseline Renovation Measures:**
    - **Envelope:** Standard insulation in place with some areas lacking full thermal performance. Plans to improve the overall insulation in future renovations.
    - **Fenestration:** Double-glazed windows, but some older units are inefficient.
    - **HVAC:** District heating system in place, but energy consumption is high due to inefficiencies in heat distribution and regulation.
    - **RES (Renewable Energy Systems):** No current renewable energy installations; potential for solar thermal in future upgrades.

Results of CCI in Pilots

Within the following sub-sections, the social impact KPI of monthly comfort compliance is presented as an integrated comfort indicator designed to evaluate indoor environmental quality across multiple domains. The CCI is further analyzed in relation to monthly mean temperature to identify meaningful patterns between environmental conditions and occupant comfort. This comparison supports the identification of trends and provides evidence-based insights that can inform and prioritize future renovation strategies aimed at improving indoor comfort, wellbeing, and overall living quality.

Aspra Spitia

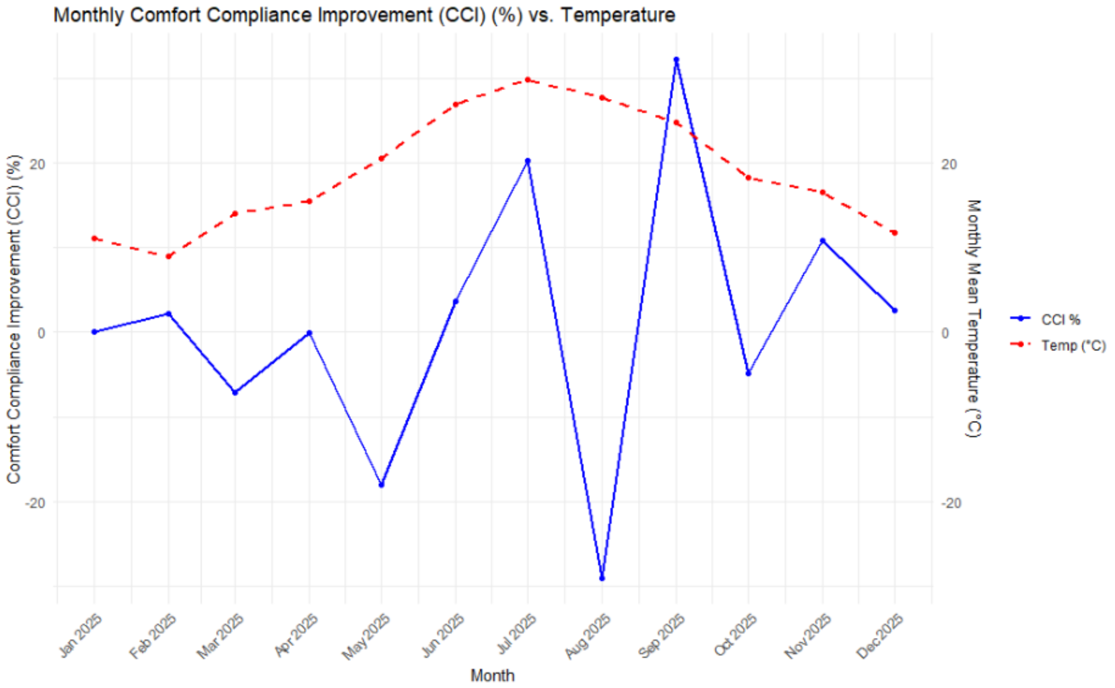


Figure 1: Monthly Comfort Compliance Improvement vs. Monthly mean Temperature for Aspra Spitia (Apartments)

Observations and recommendations for Aspra Spitia are stated as follow:

CCI Increases during warmer months

- The plotted data Figure 1 shows that the Comfort Compliance Improvement (CCI) tends to increase during the warmer months, especially from May to July, indicating that the building performs better under milder and warmer conditions, with less thermal stress on occupants.

Disproportional drop in August

- The sharp decrease observed in August is not indicative of poor building performance. Instead, it is explained by low occupancy, as most residential units were unoccupied during this period. This highlights the importance of considering occupancy patterns when interpreting monthly CCI changes.

CCI tracks monthly mean Temperature patterns

- Overall, the CCI closely follows the seasonal temperature trend, rising in warmer months and slightly decreasing during colder months. This suggests that the building’s thermal and environmental systems respond predictably to outdoor climatic conditions.

General renovation measures to improve comfort compliance

- Targeted renovations can increase baseline comfort and reduce seasonal volatility in CCI, providing a latency effect that preserves stable comfort even under extreme outdoor conditions. Key measures include:

  - Enhanced Building Envelope: Improved insulation upgraded glazing (low-e or triple-glass windows), and airtightness to reduce thermal losses and gains.
  - Optimized HVAC Systems: Efficient heating, cooling, and ventilation with demand-controlled operation to maintain thermal comfort while reducing energy use.
  - Shading and Solar Control: External shading devices, reflective coatings, or dynamic blinds to mitigate overheating during summer months.
  - Thermal Mass Enhancement: Adding thermal mass (e.g., concrete floors or internal walls) to smooth indoor temperature fluctuations.
  - Occupancy-Aware Controls: Smart systems that adapt indoor conditions based on occupancy patterns, particularly useful in seasonal or intermittent-use residential buildings.

Overall remark

- Implementing these renovation measures or part of them can smooth the seasonal fluctuations in CCI, improving overall comfort compliance and reducing vulnerability to weather conditions. The data confirms that the building would likely maintain higher CCI levels even during colder or hotter months.

Zaragoza Vivienda

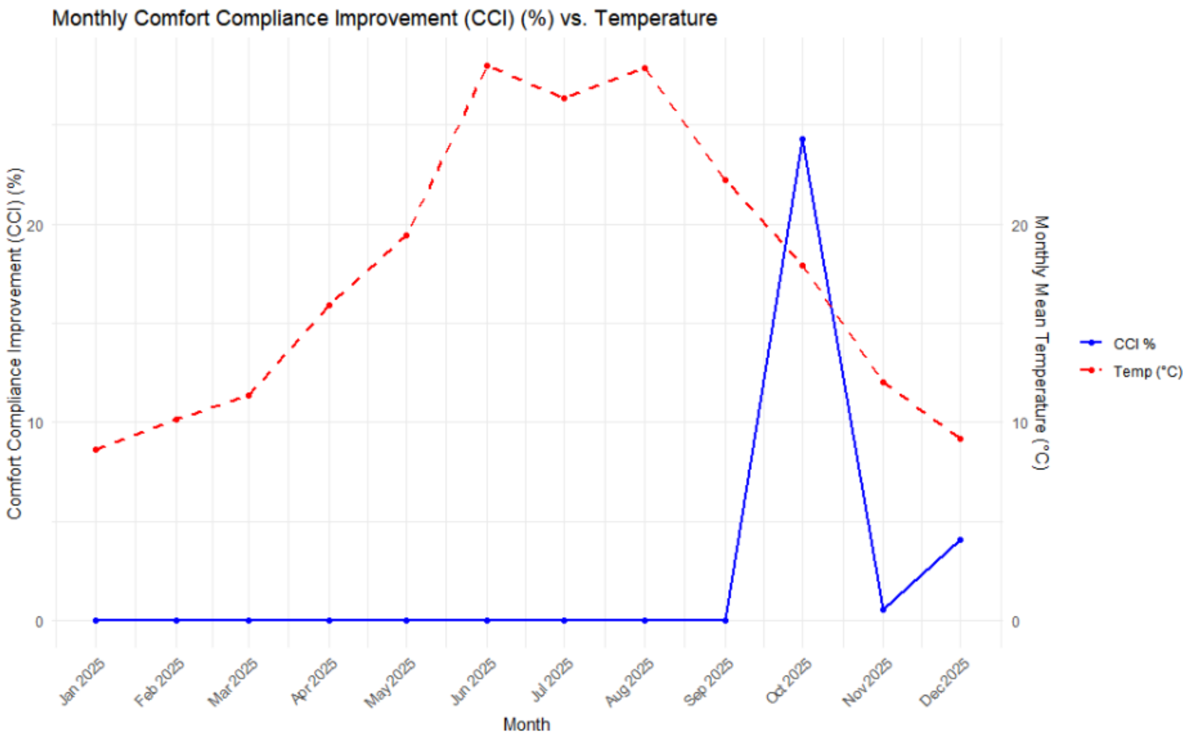


Figure 2: Monthly Comfort Compliance Improvement vs. Monthly mean Temperature for Ecce Homo 8-Zaragoza

Observations and recommendations for Ecce Homo 8-Zaragoza are stated as follow:

CCI tracks monthly mean Temperature patterns

- The CCI in Figure 2 illustrate a close tendency following the seasonal temperature trend. This suggests probably that the building's thermal and environmental systems respond predictably to outdoor climatic conditions.

Disproportional drop in November

- The sharp decrease observed in November is not indicative of poor building performance. November was the month that residents were not fully using all spaces and facilities due to renovation measures on site.

Overall remark

- More data on site requested for the post renovation analysis to confirm that the building would likely maintain higher CCI levels even during colder or hotter months.

LaSosta Massagno

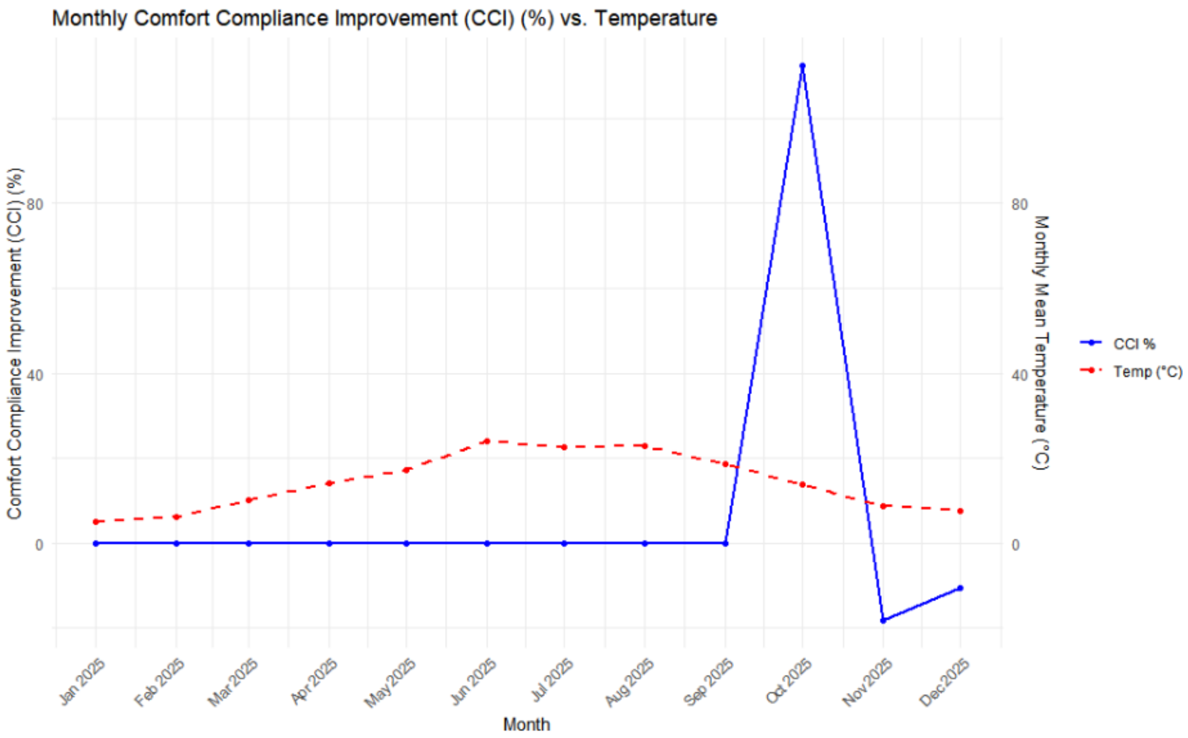


Figure 3: Monthly Comfort Compliance Improvement vs. Monthly mean Temperature LaSosta Massagno

Observations and recommendations for LaSosta are stated as follow:

Overall remark

- More data on site requested for the post renovation analysis to confirm that the building would likely maintain higher CCI levels even during colder or hotter months.

Results of ECA in Pilots

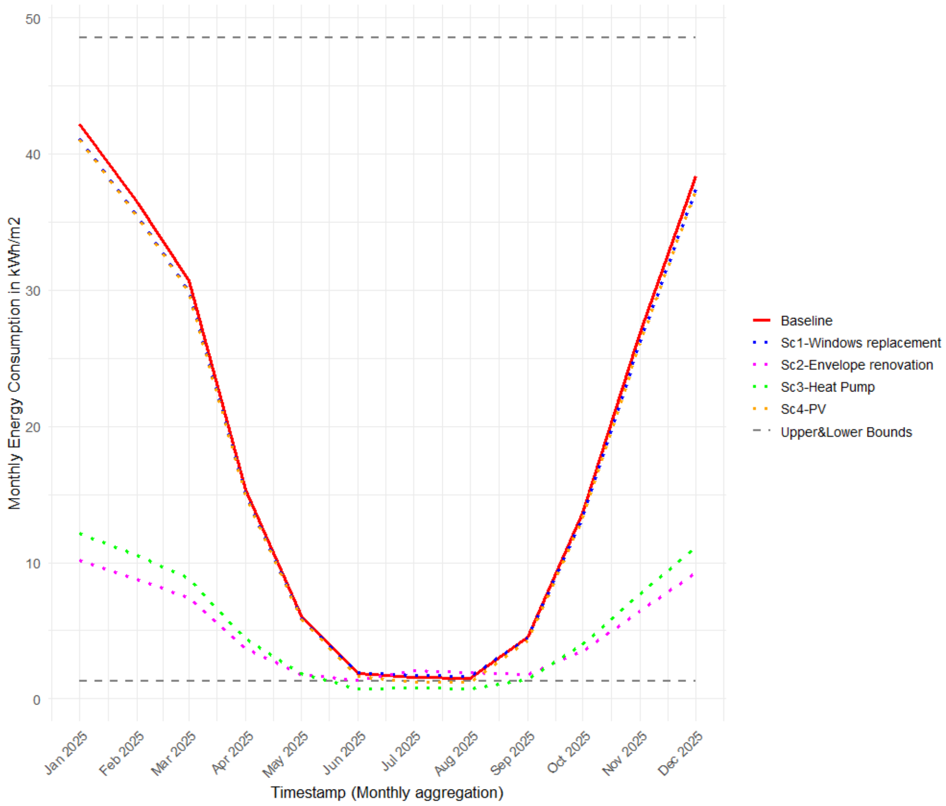
The Energy Consumption Awareness Impact KPI results for the five residential pilots in Greece, Spain, Switzerland, Ireland, and Denmark demonstrate how different renovation scenarios influence total final energy consumption per square meter relative to each asset's defined baseline. For each Pilot, the first illustration presents the aggregated monthly baseline energy intensity (kWh/m²) alongside the simulated renovation scenarios and their project-specific upper and lower performance boundaries. This visualization highlights the seasonal profile of energy demand and enables direct comparison between baseline operation and intervention strategies under varying climatic conditions. The second illustration presents the corresponding Energy Consumption Awareness (ECA) impact KPI, calculated as the difference between the scenario score and the baseline score, thereby quantifying the relative improvement or deterioration in energy awareness and performance.

ΔEnergy Awareness.

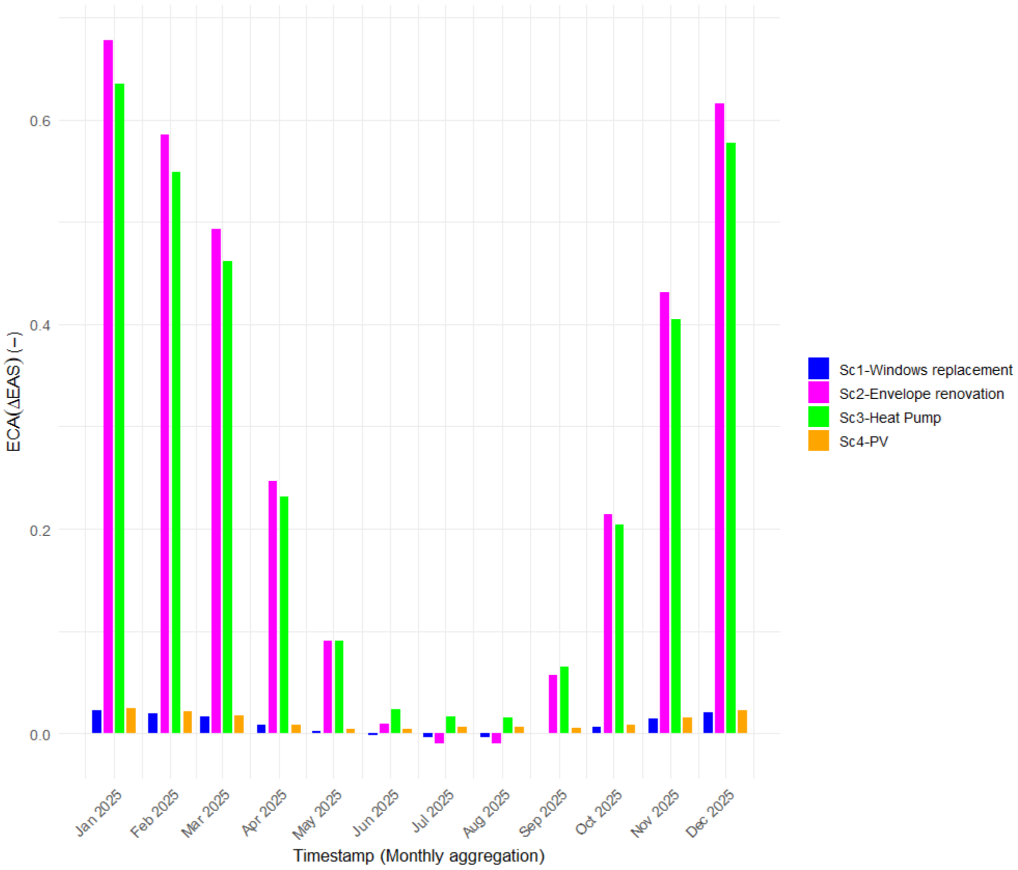
Positive values indicate enhanced energy efficiency and stronger alignment with energy-conscious design and operation, while negative values signal performance regression or insufficient impact. Across the five pilots, the KPI enables consistent country based specific comparison on different renovation scenarios despite climatic differences, as normalization per square meter and scenario benchmarking ensure methodological coherence. Together, the two visualizations provide both a physical performance perspective (energy intensity evolution) and a normalized impact assessment (KPI delta), supporting transparent evaluation of renovation effectiveness and strategic decision-making.

Although the ECA impact KPI is not intended to identify a single optimal renovation scenario, an optional cost analysis was conducted exclusively for the Aspra Spitia to estimate operational expenses and support the prioritization of commonly applicable renovation scenarios within this specific context. This pilot-focused cost assessment as illustrated in Figure 4(c), is provided as a complementary guidance feature, rather than a prescriptive evaluation, aiming to reflect local energy pricing conditions and consumption patterns. The estimated operational costs and potential revenues associated with each renovation scenario can support professional stakeholders in making more informed, context-sensitive decisions during the final selection process.

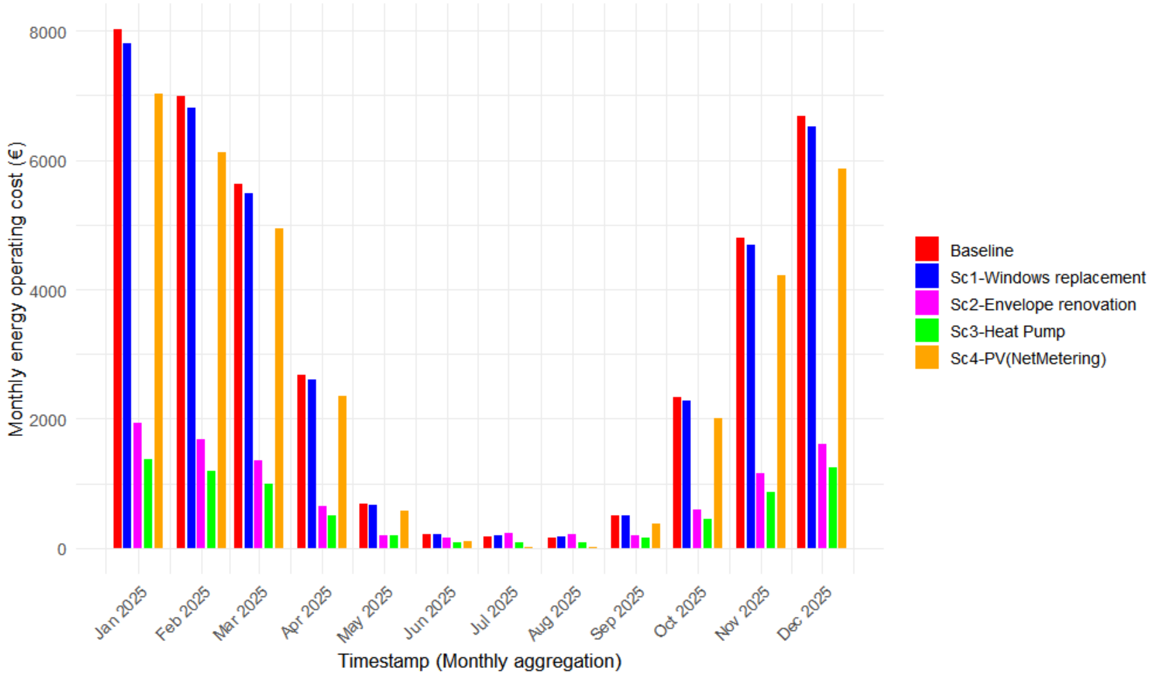
Aspra Spitia



(a)



(b)



(c)

Figure 4: Monthly energy consumption (kWh/m²) and proposed renovation scenarios for Aspra Spitia apartments shown in (a); Energy Consumption Awareness (ECA), expressed as a dimensionless comparison between scenarios and baseline, in (b); and monthly energy operating cost assessment of the baseline and renovation scenarios in (c).

Assessment of Renovation Scenarios for Aspra Spitia

The monthly energy consumption results for Aspra Spitia illustrated in Figure 4(a) reveal a pronounced seasonal pattern characteristic of heating-dominated Mediterranean climates. The baseline profile exhibits a clear U-shaped annual curve, with the highest values occurring during the winter months (January–March and November–December) and the lowest values observed during the summer period (June–August). This pattern indicates that space heating demand is the primary driver of energy consumption in the assessed building stock, while summer energy requirements remain comparatively limited. The minimum values during July and August confirm the negligible influence of heating during this period and suggest that cooling demand does not significantly affect the selected energy indicator.

A comparison of the four renovation scenarios illustrated in Figure 4(b) highlights notable differences in performance and effectiveness. To support scenario prioritization, a cost analysis was conducted complementary only for the Aspra Spitia settlement as illustrated within Figure 4(c), to estimate operational expenses and potential revenues.

The monthly baseline energy consumption values (kWh/m²), as shown in Figure 4(a), were used as direct inputs for the operational cost calculation. Energy demand was converted into monetary values using appropriate monthly unit energy prices described as follows.

Energy Price Assumptions for Aspra Spitia

- Electricity tariff: €0.072/kWh (reduced tariff applicable in Aspra Spitia).
- Heating oil: Monthly average retail prices (€/litre), converted to €/kWh using the standard Lower Heating Value (LHV):

1 lit heating oil = 10.35 kWh

Price (€/kWh) = Price (€/lit) / 10.35

Monthly Energy Cost for Aspra Spitia

As the analysis focuses on heating performance:

- During the heating season (October–April), monthly baseline consumption was valued using the corresponding heating oil price (€/kWh). Although dwellings are equipped with both oil boilers and air-conditioning units, user heating behavior may vary. To avoid underestimation of winter operating costs and given that electricity tariffs (€0.072/kWh) remained consistently lower than heating oil prices during the examined period, oil pricing was adopted as a conservative baseline assumption.
- During the non-heating season (May–September), consumption was valued using the electricity tariff (€0.072/kWh).

Scenario 1 (Windows Replacement) demonstrates only marginal deviation from the baseline curve across the entire year. Although minor reductions are visible during winter months, the overall impact remains limited. This suggests that transmission losses through windows are not the dominant contributor to energy demand in this case, or that the existing window performance is already relatively moderate. As a standalone measure, window replacement does not significantly alter the seasonal energy profile of the building.

Scenario 2 (Envelope Renovation) provides a more visible reduction in ECA values, particularly during peak heating months. The improvement is most pronounced in winter, reflecting reduced heat losses through walls and other opaque elements. However, while envelope improvements lower overall demand, they do not fundamentally change the shape of the seasonal curve. The building remains heating-driven, and the magnitude of reduction, though meaningful, is moderate relative to other interventions. Envelope renovation can therefore be considered an effective passive measure, but not transformative when implemented alone.

Scenario 3 (Heat Pump Installation) delivers the most substantial improvement compared to all scenarios. The ECA curve in Figure 4(b) for this option lies consistently below the others, particularly during winter months when heating demand is highest. The reduction in peak winter values is significant, indicating that improvements in system efficiency yield stronger impacts than passive measures alone. The heat pump scenario demonstrates the largest absolute and relative reduction in energy consumption across the year. Importantly, it reduces both peak demand and total annual demand, making it the most technically impactful intervention in the assessed conditions. This result underscores the importance of system-level efficiency upgrades in heating-dominated climates such as that of Aspra Spitia.

Scenario 4 (Photovoltaic Installation) shows modest reductions compared to the baseline. The impact appears slightly more visible during periods with higher solar availability, however the effect remains limited during winter months when heating demand is at its peak. This outcome suggests that while photovoltaic systems contribute to on-site electricity generation, their influence on a heating-dominated energy indicator is constrained, particularly if the heating system is not fully electrified or if generation does not directly offset the dominant demand component. PV installation can therefore be regarded as a complementary strategy rather than a primary demand-reduction measure in this specific context.

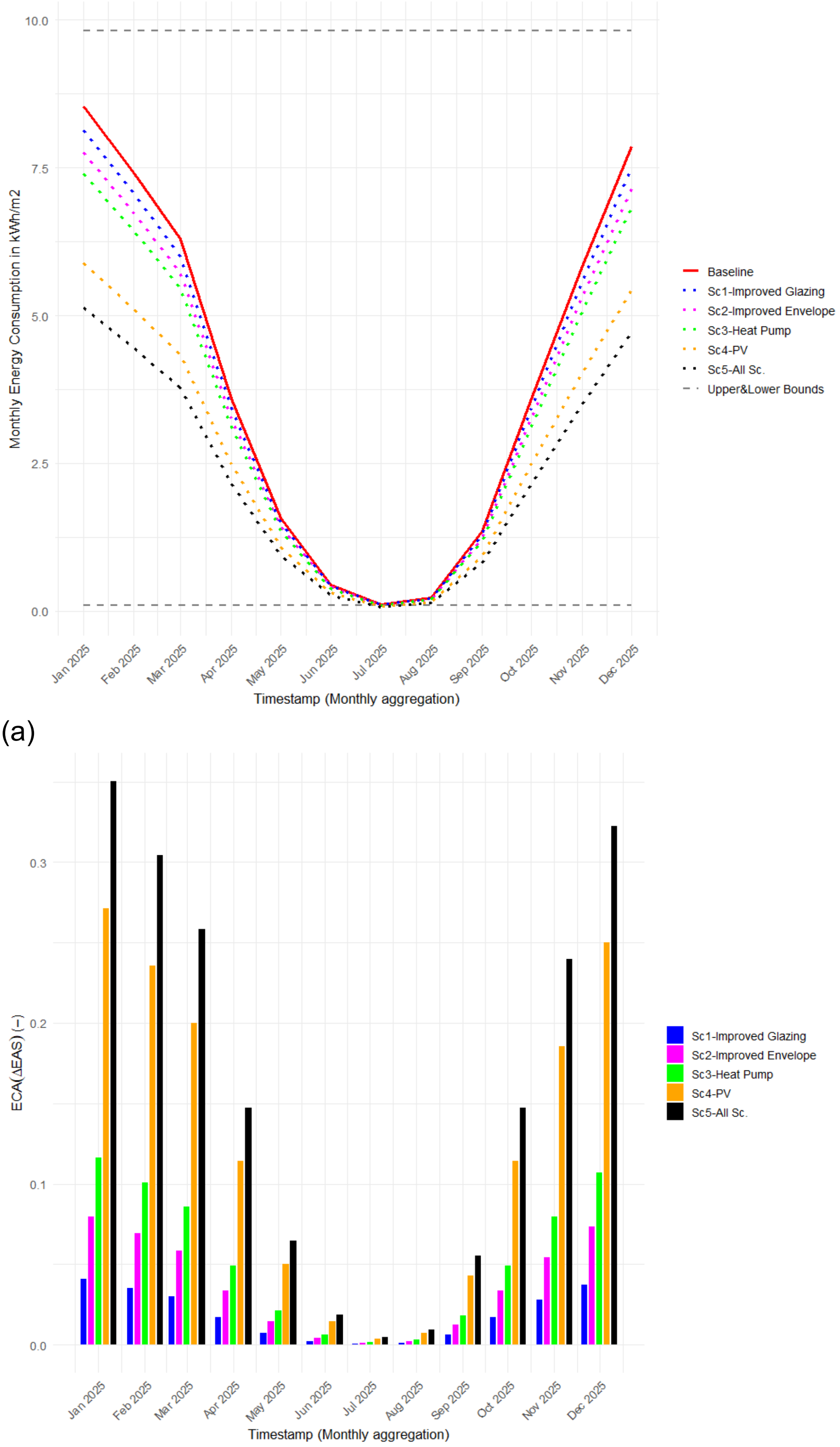
The upper and lower operational bounds illustrated in Figure 4(a) indicate that all scenarios remain within acceptable performance ranges throughout the year. No abnormal fluctuations or instability are observed, suggesting that each intervention maintains system reliability and predictable seasonal behavior.

Overall, the ranking of renovation effectiveness for Aspra Spitia can be summarized as follows: Heat Pump Installation (highest impact), following by Envelope Renovation and Photovoltaic Installation, while the lowest standalone impact is windows replacement.

These findings highlight that in heating-dominated Mediterranean regions, improvements in heating system efficiency produce greater reductions in energy consumption than envelope renovation measures alone. Passive measures remain valuable, particularly for reducing peak losses, but system upgrades appear to offer the strongest performance gains. Photovoltaic systems, while beneficial for renewable energy integration, do not substantially modify heating-driven consumption patterns unless combined with electrified high-efficiency systems.

From a strategic perspective, prioritizing heat pump retrofitting in Aspra Spitia would likely yield the most significant energy performance improvement. Envelope renovation could serve as a secondary enhancement to further reduce thermal losses, while window replacement and photovoltaic installations may be best considered as complementary interventions within an integrated renovation strategy.

Zaragoza Vivienda



(a)

(b)

Figure 5: Monthly energy consumption in kWh/m2 and proposed renovation scenarios for Ecce Homo 8-Zaragoza in (a) and the Energy Consumption

Awareness (ECA) in (b) as a dimensionless measure between scenarios and baseline.

Assessment of Renovation Scenarios for Zaragoza – Vivienda (Ecce Homo 8)

The monthly energy consumption results for the Zaragoza residential case (Ecce Homo 8) illustrated in Figure 5(a) demonstrate a clear seasonal dependence driven primarily by heating demand. The heating degree day (HDD) distribution confirms a typical continental Mediterranean climate pattern, with high heating requirements during winter (January–March and November–December) and minimal demand during summer months (June–August). Consequently, ECA values peak during winter and progressively decline toward late spring and summer, reflecting reduced heating-related energy intensity. The seasonal gradient in Zaragoza is slightly more moderate compared to highly heating-dominated regions, but winter energy demand remains the dominant driver of performance variation. The baseline values indicate increasing efficiency stress during colder months, consistent with the HDD profile. A comparative assessment of the five renovation scenarios illustrated also in Figure 5(b) reveals important performance differences.

Scenario 1 – Improved Glazing. Scenario 1 shows modest reductions in energy consumption compared to the baseline. The ECA values remain relatively low but indicate only incremental improvements during peak heating months. The effect is most visible in January–March, where reductions correspond to lower transmission losses through glazed surfaces. However, the magnitude of improvement suggests that glazing alone does not substantially modify the building's overall thermal performance. As in many Mediterranean dwellings, window replacement contributes to comfort and localized heat-loss reduction but does not represent the primary energy-saving driver when implemented independently.

Scenario 2 – Improved Envelope. The envelope improvement scenario provides a more pronounced reduction than glazing alone. ECA values increase relative to Scenario 1 (reflecting greater efficiency gains within the defined indicator framework), especially during winter months with high HDD values. This scenario demonstrates the expected behavior of passive building improvements, i.e., reduced transmission losses lead to lower heating demand during colder periods. Nevertheless, while envelope renovation enhances thermal performance, the seasonal pattern remains largely unchanged. The intervention reduces magnitude but not the structural heating-driven nature of the consumption profile.

Scenario 3 – Heat Pump Installation. The heat pump scenario delivers stronger performance improvements compared to passive measures alone. The ECA values in Figure 5(b) indicate a substantial reduction in effective energy consumption, particularly during winter peaks. The improved system efficiency directly affects the most energy-intensive months, leading to significant annual performance gains. The data suggests that system-level efficiency upgrades provide greater impact than envelope-only interventions. In heating-driven climates such as Zaragoza, replacing conventional heating systems with high-efficiency heat pumps reduces delivered energy demand more effectively than envelope replacing measures alone. This confirms that technological upgrades addressing generation and conversion efficiency are highly influential in residential energy performance.

Scenario 4 – Photovoltaic (PV) Addition. The photovoltaic scenario produces a markedly different behavior. Monthly consumption and ECA values show significantly larger improvements compared to Scenarios 1–3, particularly during periods with higher solar radiation availability. Unlike passive measures that reduce demand, PV contributes by offsetting grid electricity consumption. Consequently, its impact is visible across a broader seasonal range and not limited solely to winter months. However, its effectiveness in reducing heating-related peaks depends on the degree of electrification of the heating system. PV appears to generate stronger relative gains than glazing or envelope measures when evaluated through the ECA indicator, particularly during mid-season and summer periods.

Scenario 5 – Integrated Renovation (Glazing + Envelope + Heat Pump + PV). The combined scenario yields the highest overall performance improvement. ECA values are consistently the most favorable across all months, indicating cumulative and synergistic effects of passive and active measures. The integration of (i) Reduced transmission losses (glazing and envelope), (ii) Improved system efficiency (heat pump) and (iii) Renewable electricity generation (PV), produces the most substantial annual performance gain. Importantly, this scenario not only lowers winter peaks but also improves overall annual balance, demonstrating the benefits of a holistic renovation strategy rather than isolated interventions.

Overall Ranking of Effectiveness (Zaragoza)

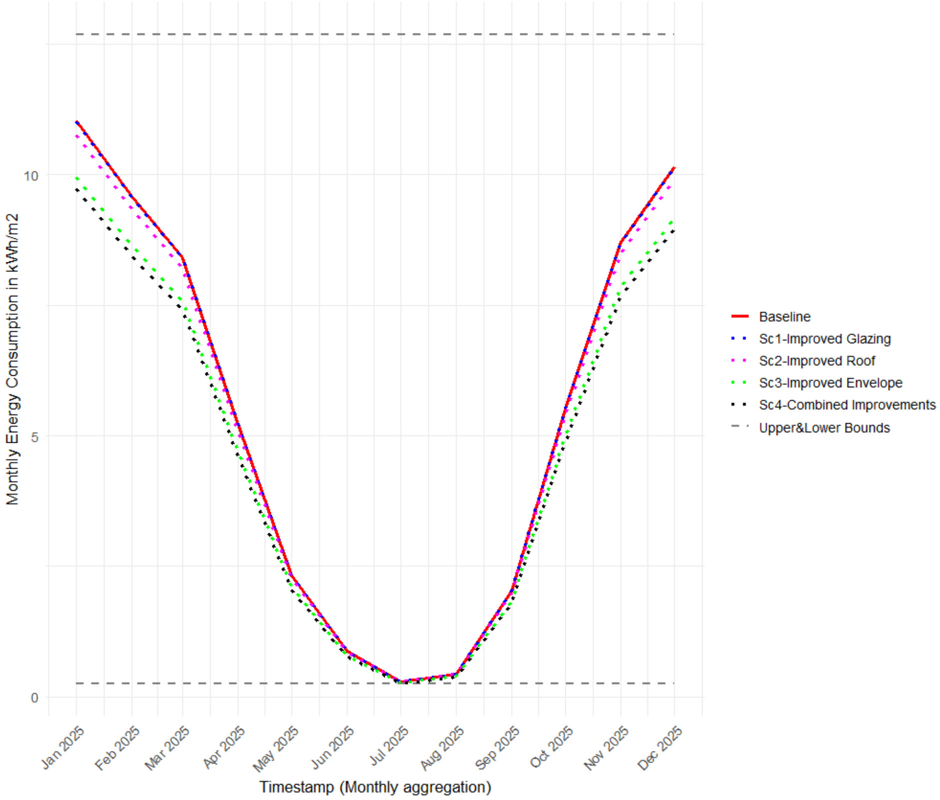
Based on the ECA indicator, Scenario 5 – Integrated Renovation shows the highest impact following by Scenario 4 – PV Addition, Scenario 3 – Heat Pump, Scenario 2 – Improved Envelope and Scenario 1 – Improved Glazing as the lower impact. This ranking differs slightly from the Aspra Spitia case, where the heat pump was the dominant standalone measure. In Zaragoza, the photovoltaic system shows stronger relative performance due to climatic solar availability and the interaction between electricity use and renewable generation.

The results indicate that energy demand in Zaragoza is predominantly heating-driven, although the strong solar resource significantly enhances the effectiveness of renewable integration strategies. Passive renovation measures, such as improved glazing and envelope insulation, contribute to incremental reductions in energy demand; however, they do not fundamentally alter the seasonal structure of consumption, which remains closely linked to winter heating requirements. The installation of a heat pump delivers substantial efficiency improvements during colder months, directly addressing the period of highest demand. Photovoltaic integration plays a more prominent role in Zaragoza than in purely heating-dominated contexts, due to favorable solar availability and its interaction with electrified systems. The combined renovation scenario demonstrates the most stable and robust performance throughout the year, indicating that synergistic effects between passive and active measures lead to the greatest overall benefit.

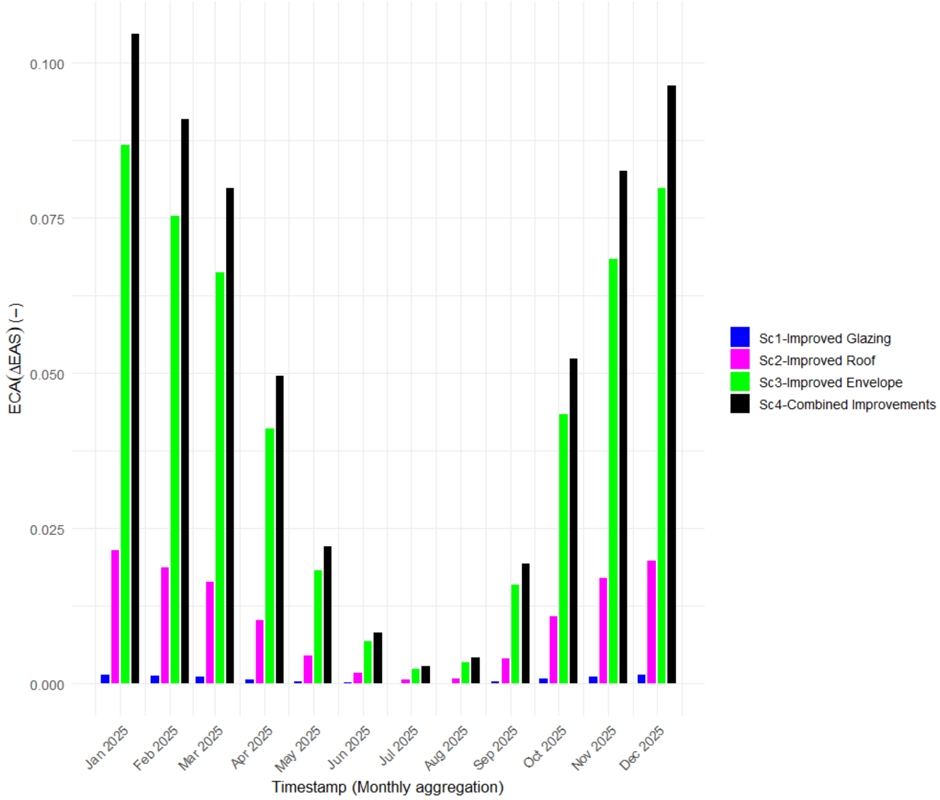
Strategic Implications

For residential buildings in Zaragoza, the findings suggest that a comprehensive renovation strategy yields the highest performance gains. Integrating photovoltaic systems is particularly advantageous under local climatic conditions, where solar radiation levels enhance renewable generation potential. Heat pump deployment should be prioritized in cases where heating electrification is technically and economically feasible, as it substantially improves winter efficiency. Envelope and glazing improvements remain important elements of renovation planning, however their impact is maximized when implemented as part of a broader integrated strategy rather than as standalone interventions. Overall, the results demonstrate that within Zaragoza’s climatic context, combining renewable energy generation with system efficiency upgrades produces stronger and more consistent performance improvements than isolated fabric measures. A multi-measure approach therefore represents the most resilient and forward-looking pathway toward long-term energy performance enhancement and decarbonization objectives.

LaSosta Massagno



(a)



(b)

Figure 6: Monthly energy consumption in kWh/m2 and proposed renovation scenarios for LaSosta-Massagno in (a) and the Energy Consumption

Awareness (ECA) in (b) as a dimensionless measure between scenarios and baseline.

Assessment of Renovation Scenarios for La Sosta, Massagno (Switzerland)

The monthly ECA (ΔEAS) results for La Sosta illustrated in Figure 6(b) reflect a climate pattern with pronounced winter heating demand, consistent with Swiss temperate conditions and the use of a 20°C heating base temperature. The HDD distribution confirms substantial winter severity, with peak values occurring in January, February, and December, and significantly reduced heating demand during summer months. The baseline seasonal profile exhibits a clear winter-dominated structure, with energy performance pressures concentrated in the colder part of the year and minimal demand during June to August as illustrated within Figure 6(a). Compared to Mediterranean cases, the Swiss context shows a stronger and more sustained heating requirement across transitional seasons, reinforcing the importance of envelope performance in annual energy balance.

Scenario 1 (Improved Glazing), which considers improved glazing, produces only marginal deviations from the baseline. The values of the ECA metric remain extremely low across all months, indicating that window upgrades alone do not substantially alter overall building performance. Although minor improvements are visible during peak heating periods, the limited magnitude suggests that glazing is not the principal source of thermal losses in this building. The seasonal pattern remains essentially unchanged, confirming that single-component upgrades yield restricted system-wide impact.

Scenario 2 (Improved Roof measures), focusing on improved roof performance, demonstrates a more noticeable reduction compared to glazing alone. The ECA values increase relative to Scenario 1, particularly during winter months when vertical transmission losses are most critical. Roof insulation contributes meaningfully to reducing heating demand, especially in a climate where sustained winter conditions intensify upward heat losses. Nevertheless, while performance improves, the seasonal profile continues to follow the same heating-driven pattern, indicating that roof enhancement alone moderates but does not transform demand dynamics.

Scenario 3 (Improved Envelope), which represents improved envelope performance, yields substantially stronger results. The ECA values are significantly higher than in the previous scenarios, especially during peak winter months. This indicates a meaningful reduction in overall heat transmission losses through the building. Considering the climatic conditions of Massagno, comprehensive envelope upgrades effectively target the primary energy demand driver which is space heating, thereby leading to significant improvements in overall annual performance. The impact is clearly more pronounced than isolated glazing or roof measures, confirming the importance of integrated envelope upgrades in colder climates.

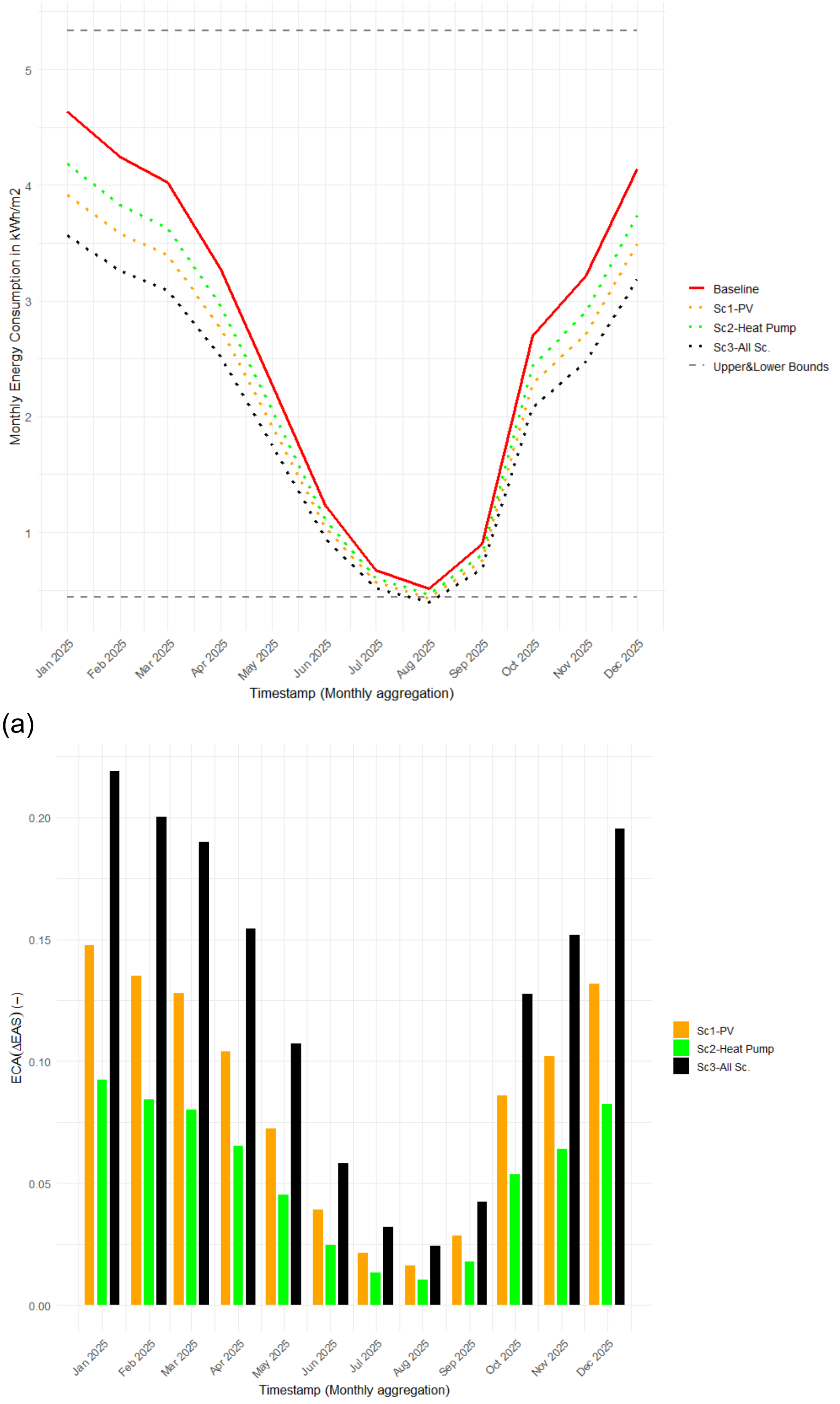
Scenario 4 (Combined Improvements), combining improvements (glazing, roof, and broader envelope measures), provides the highest overall performance improvement. The ECA values consistently exceed those of the individual interventions across all months, with the strongest effects visible during winter peaks. The cumulative effect of multiple passive measures leads to a synergistic reduction in transmission losses, thereby lowering both peak heating demand and total annual consumption. While the seasonal structure remains heating-dominated, the magnitude of demand is significantly reduced, demonstrating the effectiveness of comprehensive renovation strategies in temperate climates.

Overall, the ranking of effectiveness for La Sosta, Massagno is clearly led by the combined improvements scenario, followed by improved envelope performance, improved roof insulation, and finally improved glazing. The energy consumption dataset emphasizes the central role of envelope improvements. This outcome is consistent with the building's climatic setting and suggests that reducing transmission losses is the most impactful strategy for this case.

Strategic Implications

The results should be interpreted in the context of the existing technical baseline of the Swiss pilot, which already benefits from a relatively recent and efficient centralised heating system upgrade implemented through AEM actions. The analysed renovation scenarios therefore represent *simulated interventions on top of this current state*, rather than comparisons against a nominal or outdated system. In this context, additional equipment upgrades, such as further heat pump integration, understandably show limited marginal improvement. By contrast, envelope-related measures emerge as the most influential drivers of performance enhancement, as residual energy losses are primarily associated with the building fabric. The modest impact observed for window replacement alone is consistent with a scenario where dominant heat losses occur through walls or other structural elements, potentially including thermal bridges or façade deficiencies. Consequently, comprehensive and coordinated envelope renovation packages provide the most robust pathway for achieving long-term energy reduction, enhanced thermal comfort, and alignment with decarbonisation objectives under Swiss climatic conditions with sustained winter heating demand.

Ocualann



(a)

(b)

Figure 7: Monthly energy consumption in kWh/m2 and proposed renovation scenarios for Ocualann residentials in (a) and the Energy Consumption

Awareness (ECA) in (b) as a dimensionless measure between scenarios and baseline

Assessment of Renovation Scenarios for O’Cualann, Dublin

The monthly ECA results for the O’Cualann Pilot illustrated in Figure 7(b) reflect the characteristics of a temperate maritime climate with moderate but persistent heating demand. The heating degree day profile, calculated using a 15.5°C base temperature, indicates sustained heating requirements throughout much of the year, with peak demand occurring during the winter months of January, February, and December. Unlike more continental climates, Dublin exhibits a less extreme but longer heating season, with meaningful demand extending into spring and autumn. Consequently, the seasonal energy performance profile is heating-dominated, though without the sharp winter peaks observed in colder regions.

The baseline energy consumption illustrated in Figure 7(a) confirm this pattern, with higher performance pressure during winter months and gradual reduction toward summer. However, even in summer, energy demand does not drop to negligible levels, reflecting the relatively mild but variable Irish climate.

Scenario 1 (PV installation) demonstrates measurable improvements compared to the baseline, with ECA values indicating moderate performance gains across all months. The reductions are most significant during winter, when heating demand is highest, but the scenario also contributes to incremental improvements in transitional seasons. This suggests that the implemented measure under Scenario 1 effectively addresses part of the heating demand, though it does not fully transform the building’s seasonal energy behavior. However, the improvements are not confined solely to winter period, reflecting the broader system-level impact of renewable integration. This scenario demonstrates that in Dublin’s climate, coupling energy efficiency with renewable supply can partially enhance overall performance.

Scenario 2 (Heat Pump installation) provides a less strong improvement than Scenario 1. The ECA values are consistently lower than in the first scenario, indicating less efficiency gains across the annual cycle. The most pronounced effects are again visible during peak heating months, confirming that the intervention primarily reduces heating-related energy consumption. However, while the magnitude of improvement increases compared to baseline level, the overall seasonal structure remains largely unchanged.

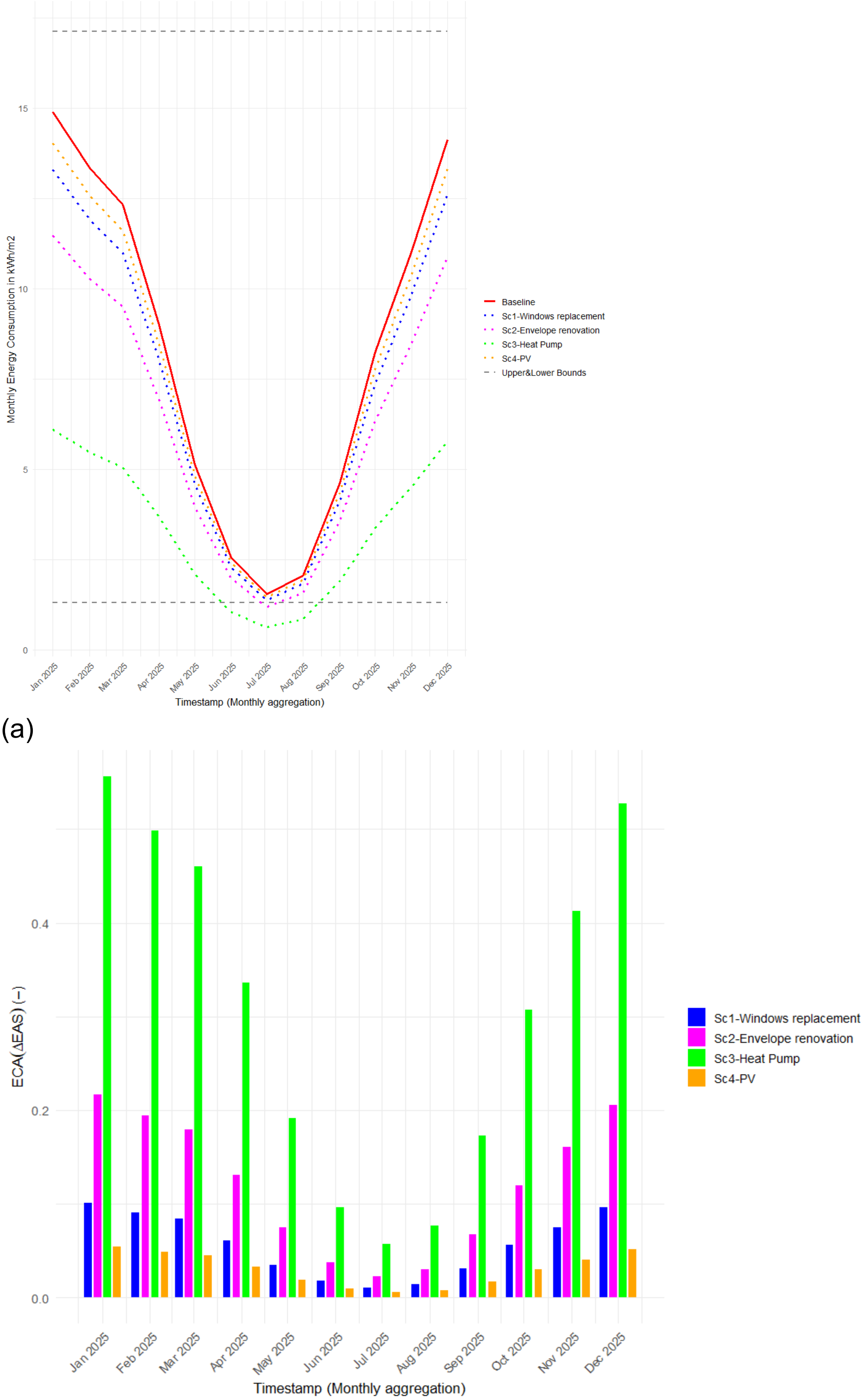
Scenario 3 (Combined improvements) The combined scenario, integrating PV energy systems and heat pump technology, yields the strongest overall results. The ECA profile illustrated in Figure 7(b) shows the highest level of performance improvement throughout the year, with particularly notable reductions during winter peaks. The integration of electrified heating with renewable energy supply produces a synergistic effect, reducing both peak demand and annual energy intensity. This comprehensive approach not only addresses heating efficiency but also decarbonizes the energy supply component, resulting in the most robust and stable performance across seasons.

Overall, the ranking of effectiveness for the O’Cualann case places the combined scenario (PV + Heat Pump) as the most impactful intervention. The results indicate that in Dublin’s temperate maritime climate, system-level upgrades and renewable integration produce stronger performance gains than incremental efficiency measures alone.

Strategic Implications

In conclusion, the findings for O’Cualann demonstrate that while heating demand remains the dominant energy driver, the relatively moderate but extended heating season benefits significantly from integrated technological solutions. Renewable energy systems, particularly when combined with heat pump technology, offer the most substantial improvements in annual performance. Individual measures contribute positively but achieve their greatest impact when embedded within a comprehensive renovation strategy aimed at both efficiency enhancement and supply decarbonization.

Herning Social Housing



(a)

(b)

Figure 8: Monthly energy consumption in kWh/m2 and proposed renovation scenarios for Herning social houses in (a) and the Energy Consumption

Awareness (ECA) in (b) as a dimensionless measure between scenarios and baseline.

Assessment of Renovation Scenarios for Herning Social Housing, Billund (Denmark)

The monthly ECA results illustrated in Figure 8(b) for the Herning Social Housing Pilot in Denmark reflect the characteristics of a cold Northern European climate with substantial and prolonged heating demand. The HDD distribution, calculated with a base temperature of 17°C, indicates very high winter severity, with peak values recorded in January, February, and March and sustained demand extending into late autumn. Compared to Mediterranean and maritime climates, the Danish context shows both higher winter intensity and a longer heating season. Consequently, the seasonal energy profile is strongly heating-dominated, with pronounced winter peaks and comparatively moderate reductions during summer months.

The baseline energy consumption illustrated in Figure 8(a) confirms this behavior, showing significant seasonal variation and elevated winter energy pressure. Even during warmer months, heating demand remains relevant, underlining the importance of measures that directly address space heating efficiency in this context.

Scenario 1 (Window replacement), focusing on windows replacement, provides measurable but moderate improvements compared to the baseline. The ECA values illustrated in Figure 8(b) indicate reductions primarily during winter months, where transmission losses through glazing are most significant. However, the magnitude of improvement remains limited relative to more comprehensive interventions. While window upgrades contribute to improved thermal performance and comfort, they do not fundamentally alter the heating-driven seasonal pattern of energy demand.

Scenario 2 (Envelope renovation), representing envelope renovation measures, delivers substantially greater improvements. The ECA values in Figure 8(b) are consistently higher than in Scenario 1 across all months, with the strongest effects visible during winter peaks. By addressing transmission losses through walls and other opaque elements, this intervention significantly reduces heating demand in a climate where external temperature differentials are large and persistent. The seasonal profile remains heating-dominated, but the overall demand level is meaningfully reduced, confirming the effectiveness of comprehensive fabric upgrades in cold climates.

Scenario 3 (Heat Pump), involving heat pump installation, produces the most pronounced performance gains compared to the individual measures. The ECA values in Figure 8(b) are markedly higher than in Scenarios 1 and 2, particularly during peak winter months when heating demand is greatest. The improvement is substantial throughout the entire heating season, indicating that system-level efficiency enhancements have a transformative impact on energy performance. In a context such as the Danish Pilot, where heating accounts for the dominant share of energy consumption, replacing conventional heating systems with high-efficiency heat pumps significantly lowers delivered energy demand and reduces peak seasonal intensity.

Scenario 4 (PV), which introduces photovoltaic (PV) integration, shows comparatively smaller improvements relative to envelope renovation and heat pump installation. While PV contributes to offsetting electricity consumption, its impact on heating-dominated demand is limited when compared to measures that directly reduce or efficiently supply space heating. The ECA values in Figure 8(b) suggest that although PV adds value, particularly during months with greater solar availability, it does not address the core driver of energy consumption in this climate to the same extent as the Heat Pump system upgrade or even envelope improvements.

Overall, the ranking of effectiveness for the Herning Social Housing case places heat pump installation as the most impactful standalone intervention, followed by envelope renovation, windows replacement, and finally PV integration. The results clearly indicate that in a cold Northern European climate, measures targeting heating system efficiency yield the strongest performance improvements. Envelope improvements also play a critical role, particularly in reducing transmission losses during prolonged winter conditions, but remains secondary in influence when heating demand is the dominant energy driver.

Strategic Implications

In conclusion, the findings demonstrate that for the Herning social housing Pilot, strategic prioritization should focus on system-level efficiency upgrades, particularly heat pump deployment, supported by comprehensive envelope renovation. Window replacement provides incremental gains but should be integrated within broader renovation measures for maximum effect. PV integration can complement these measures, especially within decarbonization strategies, but does not substitute for interventions that directly address space heating demand. The results emphasize that in strongly heating-dominated climates, technological and heating system upgrade measures targeting at winter efficiency are essential for achieving substantial and sustained energy performance improvements.

4 Tool Site Assessment Results on Pilot Sites

4.1 Overview of Demonstration Activities

Zaragoza (Spain) – Zaragoza Vivienda / Social Housing (Ecce Homo 8)

- **Demonstration focus:** full CHRONICLE workflow in a **public social-housing context**, combining technical monitoring with strong user support and engagement.
- **Activities executed:** pilot roll-out of IoB monitoring (energy + indoor conditions), validation of data flows to the CDE, and execution of renovation/operation scenarios supported by CHRONICLE tools.
- **Users involved:** building managers/technical staff and residential occupants; engagement supported through local mediation and structured feedback.
- **Tools exercised:** monitoring and facility workflows (ChroViewFM), resident-facing interaction (ChroViewOcc where applicable), and decision-support/renovation assessment tools (Renovation planning + investment/lifecycle assessment outputs where available).
- **Evidence generated:** operational datasets from sensors/gateways, user feedback, and scenario-based outputs supporting KPI calculation and cross-pilot comparison.

Mytilineos (Greece) – Aspra Spitia Residential Neighbourhood

- **Demonstration focus:** validating CHRONICLE at **neighbourhood-scale residential deployment**, leveraging existing IoT readiness and facility coordination.
- **Activities executed:** user testing and demonstration of resident-facing functions, operational monitoring across dwellings, and validation scenarios executed through the UI-first approach.
- **Users involved:** residential occupants (primary) and professional stakeholders supporting operation and interpretation.
- **Tools exercised:** ChroViewOcc for occupant interaction and feedback; system monitoring and data-driven workflows feeding into holistic assessment (CDE-connected components).
- **Evidence generated:** indoor comfort/IEQ monitoring, energy-related datasets, and structured acceptance/usability feedback used for social and comfort KPIs.

O’Cualann (Ireland) – High-Performance Residential Homes

- **Demonstration focus:** testing CHRONICLE in **high-efficiency homes** to validate decision support, benchmarking, and operational insights in digitally engaged settings.
- **Activities executed:** integration with available metering/sensing, execution of demonstration scenarios for performance interpretation, and structured stakeholder feedback on tool usefulness.
- **Users involved:** homeowners/occupants and professional stakeholders (developers/assessors/technical team).
- **Tools exercised:** energy/performance interpretation supported by the CHRONICLE ecosystem (monitoring + modelling where applicable), with professional-facing workflows for assessment and reporting.
- **Evidence generated:** comparative datasets for baseline vs CHRONICLE-supported assessment, plus user feedback capturing acceptance and perceived value.

AEM (Switzerland) – Assisted Living / Advanced Metering Context

- **Demonstration focus:** validating CHRONICLE in a **sensitive user environment**, prioritising building-level monitoring, robustness, and operational value over resident-facing interaction.
- **Activities executed:** integration of advanced metering and building system monitoring, validation of operational workflows, and stakeholder evaluation of results and usability from a professional perspective.
- **Users involved:** facility/energy managers and technical operators; limited occupant-facing activities due to context.
- **Tools exercised:** building operation and monitoring workflows (facility/energy management), data integration into the CDE, and outputs supporting cost/carbon-oriented evaluation.
- **Evidence generated:** high-quality operational data streams and professional feedback supporting technical and economic impact KPIs.

Fallaesbo (Denmark)

- **Demonstration focus:** demonstrating CHRONICLE in a **large-scale social housing** context with strong instrumentation and district heating integration.
- **Activities executed:** wide deployment of monitoring (heat/water/indoor conditions), long-period operational data logging, and cross-building scenario testing supporting robustness and scalability claims.
- **Users involved:** housing association and facility management teams, with resident participation aligned to local engagement model.
- **Tools exercised:** monitoring and operational workflows (facility-facing), data management and traceability (CDE/DBL where applicable), and scenario-based evaluation for cross-site benchmarking.
- **Evidence generated:** data-rich operational datasets enabling strong KPI calculation (energy, cost, comfort proxies) and replication insights.

Across the five CHRONICLE pilots, demonstration activities followed a common, scenario-driven approach that ensured comparability while allowing local adaptation. In all sites, the CHRONICLE ecosystem was operated through the Common Data Environment, enabling consistent data collection, traceable workflows, and reuse of validation artefacts (scenarios, feedback templates, and KPI calculation logic). Demonstrations combined operational monitoring with user interaction and decision-support workflows, generating the evidence base required for holistic impact assessment.

A shared core activity across pilots was the deployment and operation of IoB monitoring and data logging to capture energy and indoor environmental conditions over an extended period. This produced harmonised datasets that support energy, comfort, and sustainability KPIs and enabled cross-site benchmarking. In parallel, each pilot implemented structured stakeholder engagement through onboarding, training, and feedback collection, ensuring that usability, acceptance, and perceived value indicators were captured in a consistent manner. Professional user involvement (facility managers, building owners, assessors, and technical teams) was present in all pilots, while resident-facing interaction varied depending on context.

The pilots differed mainly in scale, technical starting point, and user profile, which shaped the emphasis of the demonstrations. Mytilineos (Greece) prioritised resident-facing activities and acceptance feedback, leveraging ChroViewOcc-style interaction and structured questionnaires. AEM (Switzerland) focused on building-level operational value and robustness in a sensitive assisted-living setting, therefore privileging professional evaluation and high-quality metering integration over direct occupant engagement. Fallaesbo (Denmark) provided a large-scale, data-rich environment with district heating integration and deep renovation context, strengthening evidence on scalability, interoperability, and long-term monitoring. O’Cualann (Ireland), operating in high-performance residential homes, contributed strong benchmarking potential and insights into decision-support value in digitally mature settings.

The table below summarises the relationship between the demonstration activities carried out at each pilot site and the WP2 use cases defined in D2.1. It illustrates how the common validation framework was instantiated in different local contexts, linking concrete demonstration actions to specific use cases and the corresponding evidence generated for impact assessment. This mapping clarifies the contribution of each pilot to the overall validation and impact evaluation of the CHRONICLE solution, while accounting for site-specific constraints and priorities.

Table 17: Relation between Demonstration Activities and WP2 Use Cases per Pilot

Pilot	Main Demonstration Activities	WP2 Use Cases Covered	Main Evidence Produced (for D5.3 KPIs)
Zaragoza (ES)	IoB monitoring and data logging; execution of renovation planning scenarios; facility/operation monitoring; targeted engagement and feedback activities	UC3.1a Renovation assessment + BRP; UC3.2 Carbon Bill; UC4.1 FM monitoring; UC4.2 maintenance analytics; UC2.1 occupant reporting (where applicable)	Monitoring datasets (energy/IEQ), scenario outputs (BRP), Carbon Bill outputs, FM KPI dashboards, user feedback (acceptance/usability)
Mytilineos (GR)	Resident-facing testing and questionnaires; IoB data capture at dwelling scale; professional interpretation and scenario testing; FM monitoring and maintenance-oriented workflows	UC1.1 comfort-driven renovation actions; UC2.1 occupant reporting; UC2.2 professional insights; UC3.1a renovation assessment + BRP; UC3.2 Carbon Bill; UC4.1 FM monitoring; UC4.2 maintenance analytics	Resident survey data (comfort/acceptance), monitored IEQ and energy time series, professional feedback, scenario comparison outputs, Carbon Bill and cost/carbon indicators
O’Cualann (IE)	Demonstration of performance assessment workflows; emphasis on comparing expected vs real performance (where available); user/stakeholder feedback; FM monitoring	UC3.1b post-renovation predicted vs measured; UC3.2 Carbon Bill; UC4.1 FM monitoring; UC2.1 occupant reporting (residential context)	Predicted vs measured comparison datasets, operational cost/performance evidence, Carbon Bill outputs, usability/acceptance feedback, FM monitoring KPIs
AEM (CH)	Advanced metering integration and operational monitoring; professional evaluation of outputs; renovation scenario assessment; maintenance-oriented workflows (operator-led, limited resident interaction)	UC1.1 comfort-driven renovation actions; UC3.1a renovation assessment + BRP; UC3.2 Carbon Bill; UC4.1 FM monitoring; UC4.2 maintenance analytics; UC2.1 not validated (explicit in D2.1)	High-quality energy/system datasets, FM KPI reporting, scenario and BRP outputs, Carbon Bill indicators, operator feedback and lessons learned
Fallaesbo (DK)	Large-scale monitoring in social housing; long-period data logging; emphasis on	UC1.1 comfort-driven renovation actions; UC3.1b post-renovation	Data-rich monitoring time series, predicted vs measured comparisons,

Pilot	Main Demonstration Activities	WP2 Use Cases Covered	Main Evidence Produced (for D5.3 KPIs)
	post-renovation performance validation; cross-building benchmarking; stakeholder feedback	predicted vs measured; UC3.2 Carbon Bill; UC4.1 FM monitoring; UC2.1 occupant reporting (residential context)	benchmarking-ready KPIs, Carbon Bill outputs, stakeholder feedback supporting replication

Overall, the cross-pilot demonstrations confirm that CHRONICLE can be deployed and operated under diverse European conditions while maintaining a unified evaluation framework. The combination of comparable datasets, structured user feedback, and pilot-specific adaptations enables robust aggregation of results at project level, while also identifying context-dependent factors relevant for replication and exploitation.

5 Cross-site synthesis and benchmarking

The comparison of the five CHRONICLE pilot sites highlights the influence of local energy systems, regulatory frameworks, and market conditions on the performance and applicability of the CHRONICLE tool suite. From an energy and sustainability perspective, the analysis shows that baseline building performance and renovation potential vary significantly across pilots, partly reflected in the differences in Energy Performance Certificate (EPC) ratings and building typologies.

Energy performance levels across pilot sites vary significantly, ranging from low-efficiency buildings (e.g. EPC class H in older Mediterranean contexts) to medium and high-performance buildings (EPC classes B–C in Northern and recently constructed buildings), reflecting differences in construction periods, energy systems, and national regulations.

These variations are also influenced by national electricity mixes and the availability of district heating infrastructures. For example, pilots located in regions with a higher share of renewable electricity or district heating systems benefit from lower operational carbon intensities, whereas electrification strategies may face constraints in regions with less decarbonised grids or infrastructure limitations. In addition, regulatory conditions such as heritage protection requirements can affect renovation options and therefore the achievable energy and carbon improvements. To ensure methodological consistency, carbon and life-cycle related assessments were benchmarked using recognised databases and frameworks such as the Ramboll CO_2 database, OKÖBAUDAT, and methodologies aligned with previous European initiatives such as the INDICATE project.

From an economic perspective, cross-site benchmarking confirms expected variations in renovation and operational costs across countries. Higher labour and construction costs are generally observed in wealthier regions, while energy prices do not always follow the same pattern. In some cases, countries with higher construction costs benefit from comparatively lower energy prices due to large-scale energy infrastructures, district heating networks, or national support schemes for renewable energy. These contextual differences influence the cost-effectiveness of renovation scenarios assessed with CHRONICLE tools and highlight the importance of site-specific analysis when evaluating return on investment and long-term operational savings.

Regarding business and replication aspects, the demonstrations indicate that the CHRONICLE ecosystem can support decision-making for a wide range of stakeholders, including social housing operators, facility managers, and public authorities. However, the level of market readiness varies depending on data availability, integration with existing building management systems, and the maturity of digitalisation processes in each pilot context. Indicators related to Energy Consumption Awareness (ECA) show promising trends, suggesting that the visualisation and analytics capabilities of the CHRONICLE tools can support improved understanding of building energy performance. Nevertheless, longer monitoring periods would be required to fully assess behavioural changes and long-term engagement effects. Similarly, early results related to Comfort Compliance Improvement (CCI) suggest that operational data and digital twin analysis can support better identification of comfort deviations, although the magnitude of measurable improvements depends on the duration and depth of monitoring activities.

Overall, the cross-site benchmarking confirms that while CHRONICLE tools can be applied across diverse European building contexts, their impact is strongly influenced by local energy infrastructures, regulatory constraints, and economic conditions. The comparative analysis therefore reinforces the importance of flexible deployment strategies and context-aware evaluation methodologies when assessing the scalability and replication potential of digital solutions for building performance optimisation.

6 Identified Issues and Improvements

6.1 Technical Challenges and Lessons Learned

The implementation and validation of the CHRONICLE ecosystem across the pilot sites revealed several technical challenges related to data integration, modelling practices, and the digitalisation of existing building infrastructures. One of the main challenges identified concerns the BIM modelling process, particularly in the context of existing buildings. In several pilots, BIM models were not initially available and had to be developed retrospectively, which required additional effort in data collection, geometry reconstruction, and information structuring. Even when BIM models existed, model compatibility with the requirements of the CHRONICLE tools was not always straightforward. Existing BIM models and building documentation are generally created for design or construction purposes and lack the level of detail or semantic structure needed for operational analysis, asset mapping, and integration with digital twin environments.

These challenges highlighted the importance of open standards and interoperable formats, particularly the use of IFC-based exchanges, to enable consistent data flows between BIM environments, simulation tools, and the Common Data Environment (CDE). However, differences in modelling practices and interpretation of standards across partners and pilot contexts sometimes required additional manual adjustments and mappings to ensure proper interoperability. This experience reinforces the need for clearer modelling guidelines and harmonised data structures when BIM models are intended for operational and analytical use.

Another technical challenge relates to the digitalisation of legacy building systems and equipment. In older buildings, many systems were not originally designed to support digital monitoring or integration with IoT platforms. For example, in the Zaragoza pilot, the integration of existing heating infrastructure required additional instrumentation and data translation layers in order to capture operational information from devices such as boilers that were not originally connected to digital control systems. These types of retrofitting activities illustrate the complexity of deploying advanced digital solutions in existing building stock.

Operational data quality was also influenced by user behaviour and real-life operational conditions. In several cases, occupants or facility managers modified system settings or temporarily switched off devices, which could affect the continuity or completeness of monitoring data. While this reflects realistic operational conditions, it also highlights the importance of user training, clear operational guidelines, and robust data validation mechanisms to ensure reliable monitoring and analysis.

Finally, the implementation of sustainability assessment methodologies raised considerations related to carbon accounting frameworks and emerging standards, such as the CWA Carbon Bill initiative. Aligning operational data, life-cycle assessments, and carbon accounting methodologies across different tools and databases requires careful harmonisation to ensure consistency and comparability of results.

Overall, these technical challenges provided valuable insights into the practical requirements for deploying interoperable digital solutions in real building environments. The lessons learned underline the importance of early planning of BIM modelling strategies, the adoption of open standards, the careful integration of legacy systems, and the consideration of real operational behaviours when implementing digital building performance platforms.

6.2 Data Gaps and Limitations

During the implementation and validation of the CHRONICLE framework, several data-related gaps and limitations were identified that influenced the completeness and comparability of results across pilots. One of the main challenges concerns the requirements for IFC-based data exchange and integration with the Common Data Environment (CDE). Although IFC provides a widely adopted open standard for BIM data exchange, its practical use for operational data integration revealed differences between IFC models typically generated for commercial or design purposes and those required for energy analysis or digital twin applications. As highlighted in related work on IFC integration (e.g., Aitor et al.), additional mapping and data structuring were often necessary to ensure that BIM models could support the information flows required by the CHRONICLE ecosystem.

A related limitation concerns the distinction between commercial BIM IFC models and energy-oriented IFC representations. Many available BIM models were originally developed for design coordination or construction management and therefore do not always contain the parameters required for energy modelling, operational monitoring, or life-cycle analysis. (Especially for older buildings, but also in newer construction). This sometimes required additional model enrichment or manual adjustments, increasing the effort required for integration and reducing the level of automation that could be achieved in some pilots.

Language and terminology differences also introduced practical limitations during the deployment phase. BIM models, device documentation, and monitoring systems were often configured in local languages, which created additional effort when harmonising data structures, parameter names, and device descriptions across the international consortium. While these issues were manageable, they highlighted the importance of consistent naming conventions and metadata structures in collaborative digital environments.

Another limitation concerns the availability and consistency of open databases for cost and life-cycle assessment (LCA) data. Although recognised datasets and references such as OKÖBAUDAT and other European databases were used where possible, differences in national datasets, cost structures, and environmental indicators made cross-country benchmarking more complex. This required the use of harmonised assumptions and reference sources to ensure comparability of sustainability and economic assessments across pilot contexts.

Finally, the evaluation of certain impact indicators, particularly social and behavioural KPIs, is inherently constrained by the duration of the demonstration period. Assessing changes in user behaviour, comfort perception, and energy awareness requires sufficiently long monitoring periods that include baseline measurements, controlled experimentation with digital tools, and post-use assessments. In some pilots, the available demonstration timeframe limited the ability to fully capture long-term behavioural changes, meaning that some social impact indicators should be interpreted as early signals rather than definitive long-term outcomes.

6.3 Improvement Proposals for Tools and Methodologies

Based on the experience gained during the deployment and validation of the CHRONICLE ecosystem, several improvements can be proposed to enhance the efficiency, scalability, and robustness of both the tools and the overall methodological framework. One key recommendation concerns the simplification of data flows and system integrations. While the CHRONICLE architecture enables comprehensive interoperability between multiple components, in practice the number of integrations and data exchanges can increase system complexity and implementation effort. Future deployments could benefit from prioritising essential data exchanges and establishing clearer data pipelines within the Common Data Environment (CDE), thereby reducing configuration effort and improving system stability.

Similarly, the validation activities demonstrated that focusing on a limited and well-defined set of use cases can significantly improve the clarity and effectiveness of demonstrations. While the project initially explored a broad range of potential functionalities, concentrating on the most relevant operational and decision-support scenarios allows for more robust validation and clearer communication of results to stakeholders.

From a technical perspective, improved integration of energy modelling engines through standardised APIs would facilitate more seamless interaction between simulation tools, digital twins, and operational monitoring platforms. This approach would reduce manual data transfers and support more dynamic scenario analysis, strengthening the analytical capabilities of the CHRONICLE ecosystem. In parallel, the adoption of a structured BIM Execution Plan aligned with recognised standards and open formats would help ensure that BIM models developed for projects are directly compatible with operational tools, digital twin environments, and sustainability assessment workflows. The importance of such structured digital frameworks has also been highlighted in recent research on digital twins and BIM interoperability (e.g., Aitor et al.).

Finally, methodological improvements relate to the duration and structure of pilot demonstrations, particularly when evaluating social and behavioural impacts. As observed during the project, assessing user engagement, energy awareness, and perceived comfort requires sufficiently long piloting periods that allow for baseline assessment, user familiarisation with the tools, and post-use evaluation. Future initiatives should therefore ensure longer monitoring phases and structured experimentation periods to more accurately capture the social value generated by digital building management solutions.

7 Conclusions

The overall findings of D5.3 confirm that the CHRONICLE ecosystem delivers measurable value across technical, environmental, economic, business, and social dimensions when assessed under the Common Validation Methodological Framework presented in section 2 and operationalised through the KPI framework in Section 3, the pilot-level evidence in Section 4, the collected data in annexes, and the cross-site benchmarking in Section 5. As consolidated in the Executive Summary and Project-level Impact Results, the project demonstrates that CHRONICLE improves the quality and robustness of building performance assessment, supports more informed renovation decisions, and provides a traceable and interoperable digital environment for holistic impact evaluation. The strongest demonstrated impacts concern energy, carbon, and life-cycle performance, supported by the technical and sustainability KPIs and by the methodological annexes, including 8.1 Annex: Full KPI Formulas and Calculation Process, 8.2 Annex: LCA-LCC Methodology and Inventory, and the Supplementary Material of the Human Centric KPI calculations. These sections also confirm the importance of linking dynamic thermal modelling, monitoring evidence, whole life carbon, and cost calculations in a coherent framework, in continuity with T5.2 and the methodological basis previously established in D5.2, and with the LCA/LCC approaches described in D4.3 and D4.4, as referenced in the annexes and inventory methodology.

From a replication and exploitation perspective, the results reported in Section 4 – Tool Site Assessment Results on Pilot Sites, together with the pilot-to-use-case mapping in Table 17: Relation between Demonstration Activities and WP2 Use Cases per Pilot and the evidence generated across the five demonstrations, show that CHRONICLE can be deployed under diverse European conditions while maintaining a unified validation logic. This is particularly relevant for the exploitation pathway foreseen in T6.5, as the Grant Agreement states that T6.5 should support replication activities, go-to-market strategy, and the development of CHRONICLE MMPs (Minimum Marketable Products). The business-oriented findings, including the qualitative Consulting Cost Reduction (CCR) assessment, indicate that the strongest market potential lies in professional-facing tools that reduce diagnostic effort, support renovation planning, and automate reporting, while the DBL-related KPIs demonstrate that interoperability and traceability are already at a mature level for future uptake. At the same time, the lessons reported in Section 6 show that successful replication will depend on clearer BIM planning, controlled data flows, open formats, manageable integration scope, and stronger API-based connections between modelling engines and operational platforms. These conclusions are also consistent with the technical directions referenced in the document through the IFC and Digital Twin work of Aitor et al., the CWA Carbon Bill approach, and the benchmarking resources such as OKÖBAUDAT, the Ramboll CO_2 database, and the INDICATE EU project, all of which reinforce the need for harmonised methods and interoperable digital evidence chains.

Looking ahead, the project also provides clear policy implications. The cross-site results show that the impact of digital renovation and performance tools is strongly conditioned by national electricity mixes, district heating availability, building regulations, and heritage constraints, which means that European digitalisation and decarbonisation policies must be accompanied by stronger support for interoperable data standards, digital building logbooks, and harmonised carbon and cost methodologies. In addition, the social results in Section 3.3 and the Aggregation and Evaluation Method confirm that indicators such as Comfort Compliance Improvement (CCI) and Energy Consumption Awareness (ECA) are methodologically promising, but that sufficiently long piloting periods are needed to capture behavioural change and durable social value. For this reason, future projects and policy instruments should support longer monitoring windows, baseline and post-use assessments, and structured user engagement processes if social impact is to be measured with the same robustness as environmental and economic impact.

Overall, D5.3 shows that CHRONICLE contributes not only to pilot-level optimisation, but also to the broader European agenda on building digitalisation, renovation planning, and evidence-based policy support

8 Appendixes and Annexes

8.1 Annex: Full KPI Formulas and Calculation Process

Consulting Cost Reduction (CCR) – Business KPI

Consulting Cost Reduction (CCR) measures the reduction in consulting costs resulting from the implementation of the CHRONICLE tools, compared to costs previously incurred for equivalent activities in a baseline scenario (without CHRONICLE tools adoption). The assessment is based on a comparative analysis between a baseline situation, characterised by recurring specialised consultancy services and labour dedicated to manual or non-automated tasks, and the CHRONICLE post-development scenario, where a portion of these activities is streamlined or replaced by the new CHRONICLE tools and automated functionalities.

The consulting costs in the baseline situation, basically refer to:

- technical consultant fees for evaluations, analysis, calculations
- data analysis or modeling consultant fees for reporting, analysis, and modelling
- staff time spent on manual tasks, repetitive, non-value-added tasks
- costs due to errors or inefficiencies requiring rework, verification or review by external experts

The consulting costs in the CHRONICLE post-development scenario are reduced to remaining specialist activities and staff time needed to operate and manage the tools.

Quantitative assessment of the CCR KPI would require a combination of historical data such as consulting contracts, capex/opex budgets, records from previous comparable projects. Since these data were not available within CHRONICLE, the CCR KPI was assessed through a qualitative impact analysis, which allows to take into account also indirect savings, such as fewer errors and reduced corrective consultancy, and quality improvements, reducing external reviews.

The qualitative assessment returns the following levels of reduction:

- strong reduction (**CCR >50%**)
- moderate reduction (**CCR 10–30%**)
- limited reduction (**CCR <10%**)

The methodology adopted evaluates the consulting costs of the CHRONICLE UI components under realistic conditions, in line with the common validation scenarios defined in WP5 and described in D5.2.

ChroViewFM

ChroViewFM is a web-based application that supports exploring an IFC building model alongside building performance data. ChroViewFM provides an integrated 3D BIM model visualization with dedicated tabs that allow users to switch between building element information, real-time IoT sensor data and automated KPIs (e.g. energy use, IEQ, CO_2 emissions, cost, depending on data availability).

In the baseline scenario (scenario without the adoption of ChroViewFM), building stakeholders, such as facility managers, ESCOs, and architects, rely on specialised consultants to perform BIM data extraction, analyse building performance, interpret IoT sensor outputs, and prepare integrated energy, indoor environmental quality, CO_2 emissions, and cost reports. Specifically, consulting costs typically arise from the need to hire specialists for:

- **BIM data extraction and reporting**: e.g. consultants preparing model-based inventories or verifying asset data
- **Building performance analysis**: e.g. energy audits, indoor environmental quality studies, CO_2 performance assessments
- **IoT data interpretation:** e.g. review of sensor outputs, anomaly detection, KPI creation
- **Cross-analysis** between BIM, performance and cost data
- **Ad-hoc diagnostics** performed by external experts, often requiring site visits or manual data collection

ChroViewFM consolidates these activities into a single web-based environment, enabling users to visualise the IFC building model, navigate building components, and access performance metrics and KPIs directly through automated and continuously updated dashboards. By reducing the need for manual data integration, specialist analysis, and periodic outsourced assessments, the tool lowers both external consultancy hours and internal staff time required to produce equivalent insights.

The following table summarises the qualitative evaluation of the CCR from an impact-analysis perspective, starting from the results of the online user training and testing focus groups conducted at the beginning of July 2025 and in September 2025 and reported within D5.2.

Table 18: ChroViewFM – Consulting Cost Reduction (CCR) qualitative evaluation

Consulting activity (baseline)	ChroViewFM feature reducing the activity	Evidence from testing/user feedback (qualitative)	ChroViewFM improvements for CCR	Estimated CCR (%)
BIM data extraction / model inventories	3D model view + model tree	Users navigated AND selected elements with ease; suitable for quick inventories.	Less manual BIM data extraction Lower cost of pre-audit preparation	limited reduction **<10%**
Energy & IEQ performance analysis	BIM/Performance tabs + KPIs	KPIs/graphs seen as useful for rapid interpretation of performance conditions.	Less reliance on consultants for energy diagnostics and performance assessments Fewer outsourced IEQ assessments	strong reduction **>50%**

			Automated CO_2 and energy KPIs reduce external modeling needs	
IoT data interpretation	IoT data tab with graphs	Clear graph views; faster interpretation; supports maintenance use.	Reduced time spent manually assembling/managing datasets Reduced need for external support in interpreting IoT-BIM linked data	strong reduction **>50%**
Cross-analysis & reporting for different audiences	KPI tab (snapshot reports)	KPIs combined on one page; supports tailored snapshots (owners vs technicians).	Faster internal reporting (no outsourcing for KPI dashboards)	moderate reduction **10–30%**
Site visits for diagnostics	Remote IoT visualisation	Participants linked value to short-term problem ID and fewer site visits.	Reduced need for site visits	strong reduction **>50%**

ChroViewPlus

ChroViewPlus is a web-based professional tool designed to support building owners, facility managers, ESCOs, and other building-sector professionals in monitoring energy performance and indoor environmental conditions. The tool integrates data from building management systems (BMS) and IoT sensors to provide visual insights and actionable recommendations for optimising building operation, ensuring occupant comfort, and facilitating data-driven decision-making.

In the baseline scenario (scenario without the adoption of ChroViewPlus), stakeholders typically rely on specialised consultants to perform energy monitoring, indoor environmental quality (IEQ) reviews, anomaly detection based on sensor data, and the preparation of diagnostics or optimisation recommendations. Consulting costs usually arise from the need to hire experts for:

- **Energy performance interpretation**: e.g. analysis of electricity, heating, cooling, or HVAC efficiency trends
- **IEQ assessments:** e.g. temperature, humidity, CO_2, and VOC evaluations for comfort and regulatory compliance
- **Sensor data review and anomaly identification**: e.g. manual inspection of time-series data and preparation of diagnostic summaries
- **Performance reporting for different audiences** (owners, asset managers, ESCOs)
- **On-site inspections** performed by external experts to validate comfort problems or operational inefficiencies

ChroViewPlus centralises these activities within a unified digital environment that combines real-time sensor data, historical performance trends, exceedance event analytics, and automated Actionable Intelligence (AI) recommendations. Through integrated graphs, IEQ dashboards, and smart alerts, the tool reduces the need for manual data interpretation, decreases reliance on specialised consultants for periodic diagnostics, and supports proactive identification of performance issues. As a result, ChroViewPlus contributes to lowering external consultancy hours and staff time required to obtain equivalent insights through traditional, non-automated workflows.

The following table summarises the key findings for the CCR evaluation based on the user testing activities conducted in December 2025 and reported within D5.2.

Table 19: ChroViewPlus – Consulting Cost Reduction (CCR) qualitative evaluation

Consulting activity (baseline)	**ChroViewPlus feature reducing the activity**	**Evidence from testing/user feedback (qualitative)**	**ChroViewPlus improvements for CCR**	**Estimated CCR (%)**
Energy performance interpretation	Energy dashboards + time-series graphs	Energy trends and anomalies easy to visualise, though some metrics required clearer labels.	Reduced need for external consultants to perform periodic energy interpretation and trend analysis.	moderate reduction **10–30%**
Indoor Environmental Quality (IEQ) assessments	IEQ view + exceedance analytics	Exceedance event visualisation valuable for recognising recurring comfort/air quality issues.	Lower consultancy demand for periodic comfort/CO_2 diagnostics; easier internal identification of problematic zones.	strong reduction **>50%**
Manual review of sensor data and anomaly identification	Integrated IoT sensor data + automated alerts	Users appreciated consolidated sensor overview but noted need for clearer terminology and units.	Reduced time spent on manual sensor inspection; fewer outsourced anomaly detection tasks.	moderate reduction **10–30%**
Performance reporting for stakeholders	Unified dashboards + Actionable Intelligence	Reports and recommendations useful when thresholds and actions were clearly presented.	Faster internal reporting; fewer outsourced analyses for summaries or optimisation suggestions.	moderate reduction **10–30%**
On-site inspections for issue diagnosis	Exceedance history + remote condition verification	Remote detection of comfort/performance issues valued, especially for multi-apartment supervision.	Reduced need for on-site diagnostic visits.	strong reduction **>50%**
Operational optimisation consulting	Actionable Intelligence (recommended actions + savings)	Promising component but requires clearer thresholds and severity definitions.	Reduced reliance on consultants for routine optimisation advice; supports internal decisions.	moderate reduction **10–30%**

ChroViewRen

ChroViewRen is a web-based professional renovation planning and decision-support tool that integrates the Renovation Planner and the Investment Appraiser into a unified interface. It is designed to guide building owners, engineers, facility managers, and public housing organisations through the full process of developing renovation roadmaps, assessing energy, cost, and carbon impacts and generating Building Renovation Passports (BRPs).

In the baseline scenario (scenario without the adoption of ChroViewRen), renovation planning is a fragmented, multi-stage process that often requires extensive involvement of external consultants. Consulting costs generally arise from:

- **Pre-audit and baseline building characterisation,** including manual collection and structuring of building-level information, often requiring site visits or on-demand modelling
- **Identification and definition of renovation measures,** which typically involves technical consultants reviewing available documentation, selecting feasible measures, and explaining their implications to clients
- **Scenario development and comparison**, including performance modelling, financial evaluation, cost–benefit analysis, carbon and energy impact assessments, and preparation of technical–economic reports for decision-makers
- **Preparation of Building Renovation Passports (BRPs)** or equivalent renovation documentation, often performed by external experts due to their substantial formatting, data consolidation, and compliance requirements
- **Maintenance of material and cost databases**, which commonly requires periodic consultant updates to reflect local market changes.

Each of these steps demands specialised knowledge, and without a structured tool, organisations must frequently outsource analyses, modelling, and documentation preparation. This results in significant consulting hours, higher project costs, and slower turnaround times.

ChroViewRen replaces several labor-intensive tasks that, in the baseline scenario, typically require support from specialised consultants, external auditors, or technical experts, automating functionalities and streamlining key steps.-intensive tasks that, in the baseline scenario, typically require support from specialised

The following table summarises the qualitative evaluation of the CCR from an impact-analysis perspective, starting from the results of the online user training and testing workshop held at the end of October 2025 via Microsoft Teams and reported within D5.2.

Table 20: ChroViewRen – Consulting Cost Reduction (CCR) qualitative evaluation

Consulting activity (baseline)	**ChroViewRen feature reducing the activity**	**Evidence from testing/user feedback (qualitative)**	**ChroViewRen improvements for CCR**	**Estimated CCR (%)**
Pre-audit building assessment and data structuring	Baseline building overview + 3D model visualisation	Workflow clear and 3D model provided spatial context; some performance lag observed.	Reduced need for consultants for initial data interpretation and measure-scope definition.	moderate reduction **10–30%**
Identification and selection of renovation measures	Structured measure catalogue + 3D-linked element selection	Catalogue and model supported understanding but lacked summary and modification options.	Lower need for consultant-led measure identification; improved internal scenario definition.	moderate reduction **10–30%**
Generation and comparison of renovation plans	Automated plan generation + KPI filtering	Comparison was intuitive; KPIs clear and useful for evaluation.	Reduced reliance on consultants for technical-economic scenario comparison.	strong reduction **>50%**
Economic and performance evaluation	Integrated investment appraisal + KPI calculations	Financial indicators clear and relevant; useful for decision-making.	Less dependency on consultants for ROI and carbon-impact calculations.	strong reduction **>50%**
Preparation of Building Renovation Passports (BRP)	Automated BRP generation and export	All users successfully generated/exported BRPs; valuable communication output.	Eliminates outsourced BRP preparation and formatting tasks.	strong reduction **>50%**
Administrative updates (materials, prices, products)	Editable cost databases + product data entry	Highly valued for maintaining local relevance of cost/product data.	Reduced consultant time needed for updating or adapting cost databases.	moderate reduction **10–30%**
Guidance for complex decision-making	Integrated workflow with structured scenario progression	Users understood workflow but needed more guidance in finalisation step.	Reduced need for decision-support consultancy.	moderate reduction **10–30%**

ChroViewRen demonstrates significant potential for consulting cost reduction, particularly in areas related to scenario comparison, economic evaluation, and BRP preparation, where automated functionalities directly replace specialised consulting tasks. Most baseline activities that previously required external expertise can now be performed by building owners or facility managers using the structured workflow provided by the tool.

ChroViewDBL

ChroViewDBL is a cloud-based software designed for archiving, organising, and managing documents relevant to building operations, offering secure traceability through blockchain-based technology. Within the CHRONICLE ecosystem, ChroViewDBL functions as the central repository for information generated by other tools and components, enabling stakeholders to access, share, and interpret building records consistently over time while ensuring the integrity and authenticity of archived files.

In the baseline scenario (scenario without the adoption of ChroViewDBL), building documentation is commonly dispersed across folders, email exchanges, legacy systems, or local servers. This fragmented approach requires time to various building stakeholders related to:

- **Document organisation, classification, and audit preparation**, often requiring time to structure files according to project requirements and needs
- **Verification of document integrity**, such as confirming file versions, authenticity, or whether a document has been modified or tasks delegated to specialist consultants for compliance purposes
- **File handling and access difficulties**, often requiring time for locating, classifying, or converting files (e.g., checking whether a document is the correct version)
- **Lack of standardised classification schemes**, requiring consultants familiar with recognised frameworks to reorganise building records for audits, renovations, maintenance planning, or handovers.
- **Limited collaboration features**, which in practice leads to repeated interpretation sessions, email exchanges, and consultant time spent facilitating alignment between actors.

Overall, the absence of a unified and traceable system increases the time needed to maintain documentation quality, prepare audit-ready records, and ensure data reliability over a building’s lifecycle.

ChroViewDBL streamlines documentation workflows centralising records and improving traceability.

The following table summarises the qualitative evaluation of the CCR from an impact-analysis perspective, starting from the results of the online workshop followed by a post-session user satisfaction survey in December 2025 and reported within D5.2.

Table 21: ChroViewDBL – Consulting Cost Reduction (CCR) qualitative evaluation

Consulting activity (baseline)	**ChroViewDBL feature reducing the activity**	**Evidence from testing/user feedback (qualitative)**	**ChroViewDBL improvements for CCR**	**Estimated CCR (%)**
Document storage, retrieval, and version control	Centralised cloud repository + blockchain traceability	Repository and timeline concept considered useful for long-term documentation tracking.	Reduced need for consultants for document archiving, version tracking, and integrity verification	limited reduction **<10%**
File classification and organisation	Built-in categorisation + tagging	Tagging understood, but classification insufficient for professional needs.	Decreased reliance on consultants for audit-ready documentation structuring	limited reduction **<10%**
Document review and internal collaboration	Commenting, sharing, liking features	Collaboration features understood and seen as potentially useful.	Reduced consultant involvement in documentation review cycles.	moderate reduction **10–30%**
Verification of document integrity	Blockchain-based validation	Integrity verification seen as useful for compliance and long-term record assurance.	Reduces need for specialised consultancy for compliance validation.	moderate reduction **10–30%**
Preparation of documentation packages	Document timeline + structured repository	Easy access to file histories; UI clarity still needs improvement.	Less external support needed for assembling audit or project documentation sets.	moderate reduction **10–30%**
Checking file format compatibility and previews	In-app preview for supported formats	PDF preview worked well; IFC required downloads.	Partial reduction in consultant/IT support time for compatibility checks.	limited reduction **<10%**
Maintaining long-term digital records	Permanent archival with traceability	Concept useful; strong integration with other tools requested.	Reduced consultancy for long-term lifecycle documentation management.	moderate reduction **10–30%**

ChroViewOcc

ChroViewOcc is a mobile application designed for residential end users, providing simple and accessible visualisation of data collected through IoT sensors, including electricity consumption and indoor comfort indicators.

Although the tool targets residents rather than professionals, its introduction influences the broader ecosystem of building management and, indirectly, the consulting activities traditionally needed to support energy awareness, user engagement, and behavioural change.

The evaluation of consulting cost reduction therefore focuses on a comparison between the **baseline scenario**, where no dedicated digital engagement tool is available, and the **ChroViewOcc scenario**, where residents have real-time access to actionable information.

In the baseline scenario (scenario without the adoption of ChroViewOcc) resident engagement in energy and comfort optimisation typically relies on a combination of manual communication, adhoc guidance, and external support from housing associations, energy advisors, or consultants engaged in awareness-raising programmes. Even though the consulting component is smaller than in other professional building performance tools, especially for social housing environments, the cumulative staff and consultancy time required for the following tasks can be significant over time:-hoc guidance, and external support from housing associations, energy advisors, or consultants engaged in awareness-raising programmes. -performance tools,

- providing personalised energy saving advice to households-saving advice to households
- interpreting sensor or meter data on behalf of residents
- conducting awareness sessions or behavioural interventions
- responding to repetitive questions about bills, consumption patterns, comfort complaints, or appliance usage
- preparing informational materials or simple diagnostics for households with persistent energy or comfort issues.

With ChroViewOcc, residents gain direct, continuous access to key information previously mediated by consultants or facility staff, reducing the need for various low-complexity consulting activities.

Considering the nature of ChroViewOcc as a residentoriented tool, the early stage maturity of the app and the variability of resident needs the CCR impact is **indirect and can be classified as limited.** In fact, ChroViewOcc does not replace professional technical consultancy, but it effectively reduces demand for recurring informational and behavioural guidance tasks. enhanced resident autonomy in understanding and managing their energy use.-oriented tool,-stage maturity of the app and the variability of resident needs the CCR impact is

Table 22: ChroViewOcc – Consulting Cost Reduction (CCR) qualitative evaluation

Consulting activity (baseline)	**ChroViewOcc feature reducing the activity**	**Evidence from testing/user feedback (qualitative)**	**ChroViewOcc improvements for CCR**	**Estimated CCR (%)**
Resident-level energy awareness sessions or guidance	Real-time household energy visualisation	90% reported improved understanding; app seen as easy and useful.	Reduces need for repeated energy-awareness sessions.	limited reduction **<10%**
Interpretation of comfort complaints	Simple comfort indicators (temperature, humidity, CO_2)	Users found indicators useful after brief explanation.	Decreases reliance on advisors for basic comfort interpretations.	limited reduction **<10%**
Repetitive inquiries about bills or consumption	Accessible dashboards + simple explanations	Majority found app simple and informative; no errors reported.	Reduces staff/consultant time responding to recurring questions.	limited reduction **<10%**
Behavioural advice and low-complexity diagnostics	Trend views + insights supporting self-assessment	60% indicated app may guide energy-saving actions.	Lowers need for personalised behavioural consulting.	limited reduction **<10%**
Preparation of informational materials for residents	In-app display of values and indicators	Residents preferred seeing data directly in the app.	Decreases need for printed/external educational materials.	limited reduction **<10%**

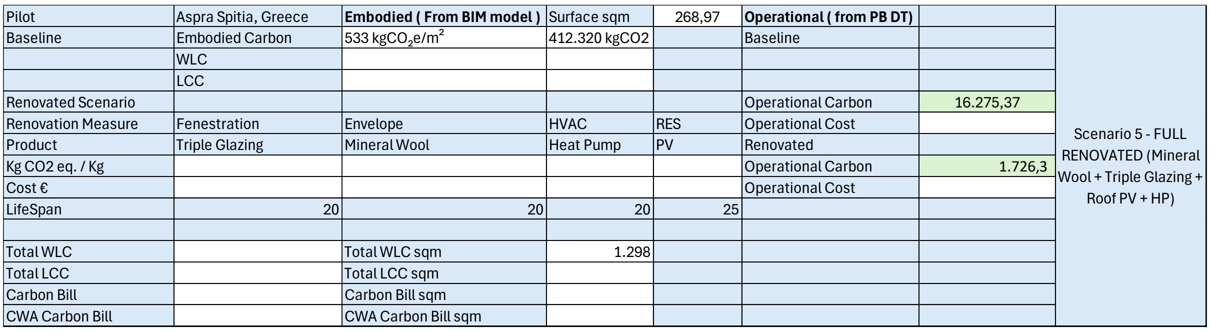
8.2 LCA- LCC Methodology and Inventory

The Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) of each pilot building were performed in accordance with the relevant ISO standards, including ISO 14040–44 for environmental assessment, EN 15804 / ISO 21930 for construction-product and building-level life-cycle rules, and ISO 15686-5 for whole-life costing. The methodological framework, formulas, system boundaries and indicator sets applied across all pilots are fully described in Deliverables D4.3 and D4.4, ensuring harmonised procedures and comparability.

For pilots composed of more than one building, renovation scenarios were selected to be as comparable as possible across the different assets; nevertheless, the comparison between each renovated building and its own baseline remains the most relevant analytical perspective. Even so, the ability to contrast results across five distinct typologies and locations also provides meaningful cross-case insights. Additionally, the calculation of the Carbon Bill—which monetises life-cycle greenhouse-gas emissions—is detailed in the CWA developed within the project, securing methodological transparency and alignment with European sustainability assessment practices.

8.3 Aspra Spitia

Table 23: Aspra Spitia baselines and renovation measures carbon values



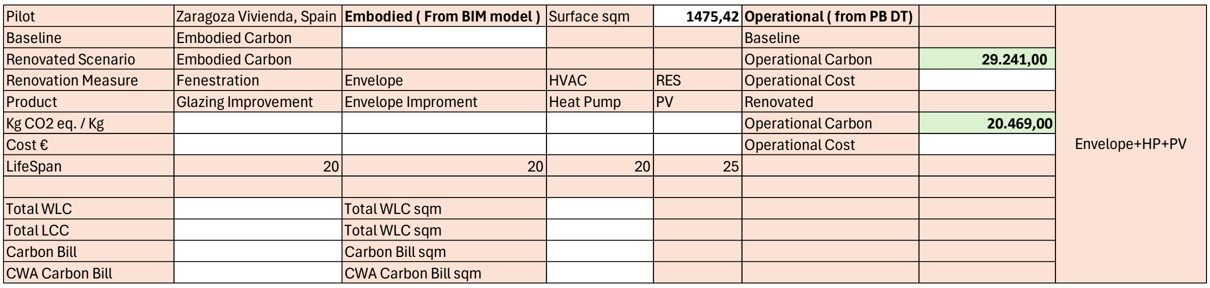
Pilot	Aspra Spitia, Greece	**Embodied (From BIM model)**	Surface sqm	268,97	**Operational (from PB DT)**		Scenario 5 - FULL RENOVATED (Mineral Wool + Triple Glazing + Roof PV + HP)
Baseline	Embodied Carbon	533 kgCO$_2$e/m^2	412.320 kgCO2		Baseline		
	WLC						
	LCC						
Renovated Scenario					Operational Carbon	16.275,37	
Renovation Measure	Fenestration	Envelope	HVAC	RES	Operational Cost		
Product	Triple Glazing	Mineral Wool	Heat Pump	PV	Renovated		
Kg CO2 eq. / Kg					Operational Carbon	1.726,3	
Cost €					Operational Cost		
LifeSpan	20	20	20	25			
Total WLC		Total WLC sqm	1.298				
Total LCC		Total LCC sqm					
Carbon Bill		Carbon Bill sqm					
CWA Carbon Bill		CWA Carbon Bill sqm					

Renovation Measure	**Embodied Carbon (kg CO$_2$/m²)**	**Total Embodied CO$_2$ (kg)**	**Cost (€/m²)**	**Total Cost (€)**	**% of Added CO$_2$**	**% of Total Cost**
Triple Glazing	35	9,414	150	40,346	29%	30%
Mineral Wool Insulation	25	6,724	80	21,518	21%	16%
Heat Pump	20	5,379	120	32,276	17%	24%
Roof Photovoltaics (PV)	40	10,759	150	40,346	33%	30%
TOTAL Renovation	**120**	**32,276 kg**	**500 €/m²**	**134,486 €**	100%	100%

Indicator	Unit	Baseline (Total)	Baseline (per m²)	Renovated (Total)	Renovated (per m²)
Initial Embodied Carbon	kg CO_2	143,350	533	143,350	533
Added Embodied (Renovation)	kg CO_2	—	—	32,276	120
Total Embodied Carbon	kg CO_2	143,350	533	175,626	653
Operational Carbon (60 years)	kg CO_2	976,522	3,630	103,578	385
Total Whole Life Carbon (WLC)	kg CO_2	**1,119,872**	**4,163**	**279,204**	**1,038**
Renovation Investment Cost	€	—	—	134,486	500
Carbon Bill (50 €/tCO_2, A+B+C)	€	55,993	208	13,960	52
CWA Carbon Bill (Stage B only)	€	48,826	181	5,179	19

8.4 Ecce Homo, Zaragoza

Table 24: Ecce Homo baselines and renovation measures carbon values



Pilot	Zaragoza Vivienda, Spain	**Embodied (From BIM model)**	Surface sqm	1475,42	**Operational (from PB DT)**		Envelope+HP+PV
Baseline	Embodied Carbon				Baseline		
Renovated Scenario	Embodied Carbon				Operational Carbon	**29.241,00**	
Renovation Measure	Fenestration	Envelope	HVAC	RES	Operational Cost		
Product	Glazing Improvement	Envelope Improment	Heat Pump	PV	Renovated		
Kg CO2 eq. / Kg					Operational Carbon	**20.469,00**	
Cost €					Operational Cost		
LifeSpan	20	20	20	25			
Total WLC		Total WLC sqm					
Total LCC		Total WLC sqm					
Carbon Bill		Carbon Bill sqm					
CWA Carbon Bill		CWA Carbon Bill sqm					

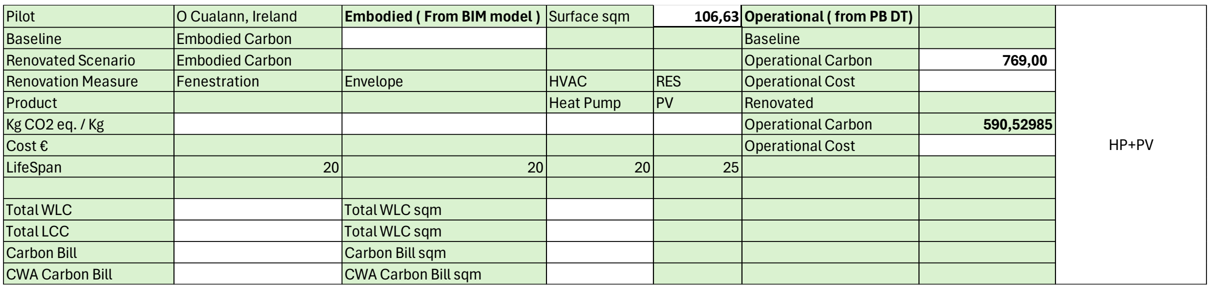
Renovation Measure	Product	Lifespan (years)	Replacements in 60y*	Added Embodied ($kgCO_2/m^2$)	Added Embodied (Total $kgCO_2$)	Cost (€/m²)	Cost (Total €)
Fenestration	Glazing Improvement	20	2	30	44,262	140	206,559
Envelope	Envelope Improvement	20	2	35	51,640	90	132,788
HVAC	Heat Pump	20	2	18	26,557	110	162,296
RES	PV (Roof)	25	2	35	51,640	140	206,559
TOTAL				**118**	**174,099**	**480**	**708,202**

Indicator	Unit	Baseline Total	Baseline /m²	Renovated Total	Renovated /m²
Embodied Carbon	$kgCO_2$	811,481	550	985,580	668
Operational Carbon (60y)	$kgCO_2$	1,754,460	1,189	1,228,140	832
Total WLC	$kgCO_2$	**2,565,941**	**1,739**	**2,213,720**	**1,500**
Total LCC	€	8,412,894	5,701 €/m²	6,816,676	4,621 €/m²
Carbon Bill (50 €/t)	€	128,297	87 €/m²	110,686	75 €/m²

Indicator	Unit	Baseline Total	Baseline /m²	Renovated Total	Renovated /m²
CWA Carbon Bill	€	87,723	59 €/m²	61,407	42 /m²

8.5 O’Cualann

Table 25: O´Cualann baselines and renovation measures carbon values



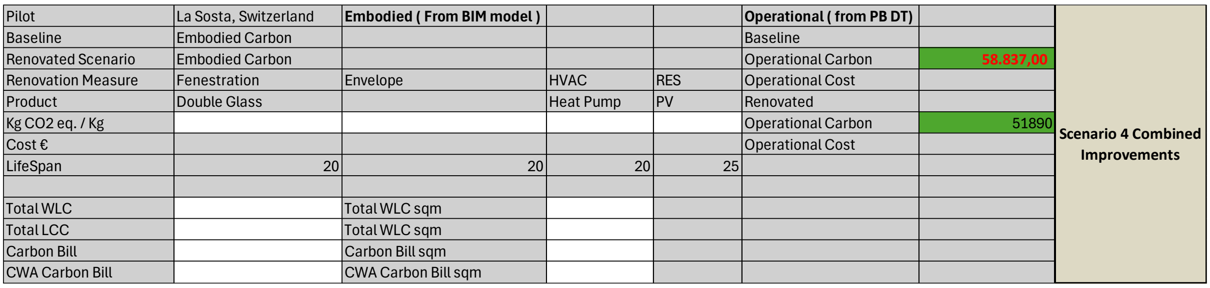
Pilot	O Cualann, Ireland	**Embodied (From BIM model)**	Surface sqm	106,63	**Operational (from PB DT)**			HP+PV
Baseline	Embodied Carbon				Baseline			
Renovated Scenario	Embodied Carbon				Operational Carbon	**769,00**		
Renovation Measure	Fenestration	Envelope	HVAC	RES	Operational Cost			
Product			Heat Pump	PV	Renovated			
Kg CO2 eq. / Kg					Operational Carbon	**590,52985**		
Cost €					Operational Cost			
LifeSpan	20	20	20	25				
Total WLC		Total WLC sqm						
Total LCC		Total WLC sqm						
Carbon Bill		Carbon Bill sqm						
CWA Carbon Bill		CWA Carbon Bill sqm						

Renovation Measure	Product	Lifespan	Replacements (60y)	Added Embodied (kgCO$_2$/m²)	Total Embodied (kgCO$_2$)	Cost (€/m²)	Total Cost (€)
Fenestration	Window upgrade	20y	2	35	3,710	160	16,960
Envelope	External insulation	20y	2	45	4,770	110	11,660
HVAC	Heat Pump	20y	2	20	2,120	130	13,780
RES	PV	25y	2	40	4,240	150	15,900
TOTAL				**140**	**14,840 kg**	**550 €/m²**	**58,300 €**

Renovation Measure	Product	Lifespan (years)	Replacements in 60y	Added Embodied (kgCO$_2$/m²)	Added Embodied (Total kgCO$_2$)	Cost (€/m²)	Cost (Total €)
Fenestration	Window Upgrade	20	2	35	3,710	160	16,960
Envelope	External Insulation	20	2	45	4,770	110	11,660
HVAC	Heat Pump	20	2	20	2,120	130	13,780
RES	Roof PV	25	2	40	4,240	150	15,900
TOTAL				**140 kgCO$_2$/m²**	**14,840 kgCO$_2$**	**550 €/m²**	**58,300 €**

8.6 La Sosta

Table 26: La Sosta baselines and renovation measures carbon values



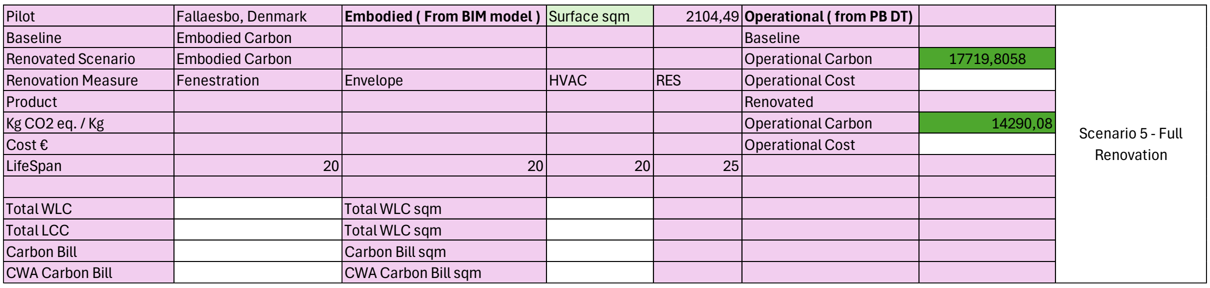
Pilot	La Sosta, Switzerland	**Embodied (From BIM model)**			**Operational (from PB DT)**		**Scenario 4 Combined Improvements**
Baseline	Embodied Carbon				Baseline		
Renovated Scenario	Embodied Carbon				Operational Carbon	**58.837,00**	
Renovation Measure	Fenestration	Envelope	HVAC	RES	Operational Cost		
Product	Double Glass		Heat Pump	PV	Renovated		
Kg CO2 eq. / Kg					Operational Carbon	51890	
Cost €					Operational Cost		
LifeSpan	20	20	20	25			
Total WLC		Total WLC sqm					
Total LCC		Total WLC sqm					
Carbon Bill		Carbon Bill sqm					
CWA Carbon Bill		CWA Carbon Bill sqm					

Renovation Measure	**Product**	**Lifespan (years)**	**Replacements (60y)**	**Added Embodied (kgCO$_2$/m^2)**	**Added Embodied (Total kgCO$_2$)**	**Cost (€/m^2)**	**Cost (Total €)**
Fenestration	Double Glass	20	2	30	75,000	220	550,000
Envelope	Insulation upgrade	20	2	45	112,500	160	400,000
HVAC	Heat Pump	20	2	20	50,000	180	450,000
RES	PV	25	2	35	87,500	200	500,000
TOTAL				**130 kgCO$_2$/m^2**	**325,000 kgCO$_2$**	**760 €/m^2**	**1,900,000 €**

Indicator	**Unit**	**Baseline Total**	**Baseline /m^2**	**Renovated Total**	**Renovated /m^2**
Embodied Carbon	kgCO$_2$	1,875,000	750	2,200,000	880
Operational Carbon (60y)	kgCO$_2$	3,530,220	1,412	3,113,400	1,245
Total WLC	kgCO$_2$	**5,405,220**	**2,162**	**5,313,400**	**2,125**
Carbon Bill (50 €/t)	€	270,261	108 €/m^2	265,670	106 €/m^2
CWA Carbon Bill (Stage B only)	€	176,511	71 €/m^2	155,670	62 €/m^2

8.7 Fallaesbo

Table 27: Fallaesbo (Herning) baselines and renovation measures carbon values



Pilot	Fallaesbo, Denmark	**Embodied (From BIM model)**	Surface sqm	2104,49	**Operational (from PB DT)**		Scenario 5 - Full Renovation
Baseline	Embodied Carbon				Baseline		
Renovated Scenario	Embodied Carbon				Operational Carbon	17719,8058	
Renovation Measure	Fenestration	Envelope	HVAC	RES	Operational Cost		
Product					Renovated		
Kg CO2 eq. / Kg					Operational Carbon	14290,08	
Cost €					Operational Cost		
LifeSpan	20	20	20	25			
Total WLC		Total WLC sqm					
Total LCC		Total WLC sqm					
Carbon Bill		Carbon Bill sqm					
CWA Carbon Bill		CWA Carbon Bill sqm					

Renovation Measure	Product	Lifespan (years)	Replacements (60y)	Added Embodied (kgCO$_2$/m²)	Added Embodied (Total kgCO$_2$)	Cost (€/m²)	Cost (Total €)
Fenestration	Timber-Aluminium Windows	20	2	25	52,612	190	399,853
Envelope	Bio-based Insulation	20	2	30	63,135	140	294,628
HVAC	Low-carbon Heat Pump	20	2	15	31,567	150	315,674
RES	Low-carbon PV	25	2	25	52,612	170	357,763
TOTAL				**95 kgCO$_2$/m²**	**199,926 kgCO$_2$**	**650 €/m²**	**1,367,918 €**

Indicator	Unit	Baseline Total	Baseline /m²	Renovated Total	Renovated /m²
Embodied Carbon	kgCO$_2$	1,473,143	700	1,673,069	795
Operational Carbon (60y)	kgCO$_2$	1,063,189	505	857,405	408
Total WLC	kgCO$_2$	**2,536,332**	**1,205**	**2,530,474**	**1,203**
Carbon Bill (50 €/t)	€	126,817	60 €/m²	126,524	60 €/m²
CWA Carbon Bill (Stage B only)	€	53,159	25 €/m²	42,870	20 /m²

8.8 Annex II Summary of Collected Data

Pilot Selection for Monitoring Analysis

Monitoring data have been collected across all Chronicle pilot sites in order to support the overall impact assessment. However, for the purpose of this section, the analysis focuses on the Dublin and Zaragoza pilot cases, which are considered representative of the monitoring framework and the types of operational data generated within the project.

These two pilots provide comprehensive datasets that reflect the implementation of the Chronicle monitoring infrastructure in real operational environments and illustrate the types of indicators derived from building monitoring systems.

The Greek pilot is not analysed in detail in this section because its impact is already addressed through the social impact KPIs, which capture the relevant outcomes related to user engagement and behavioural aspects of the project.

Similarly, the Swiss pilot relies on monitoring systems and data structures comparable to those implemented in the selected case studies. As a result, the analysis of Dublin and Zaragoza adequately reflects the type of information generated and the methodological approach applied across the different Chronicle pilot sites.

Consequently, the selected cases provide a representative overview of the monitoring-based impact assessment conducted within the project, while avoiding duplication with other sections of the report where the remaining pilots are already addressed.

SP

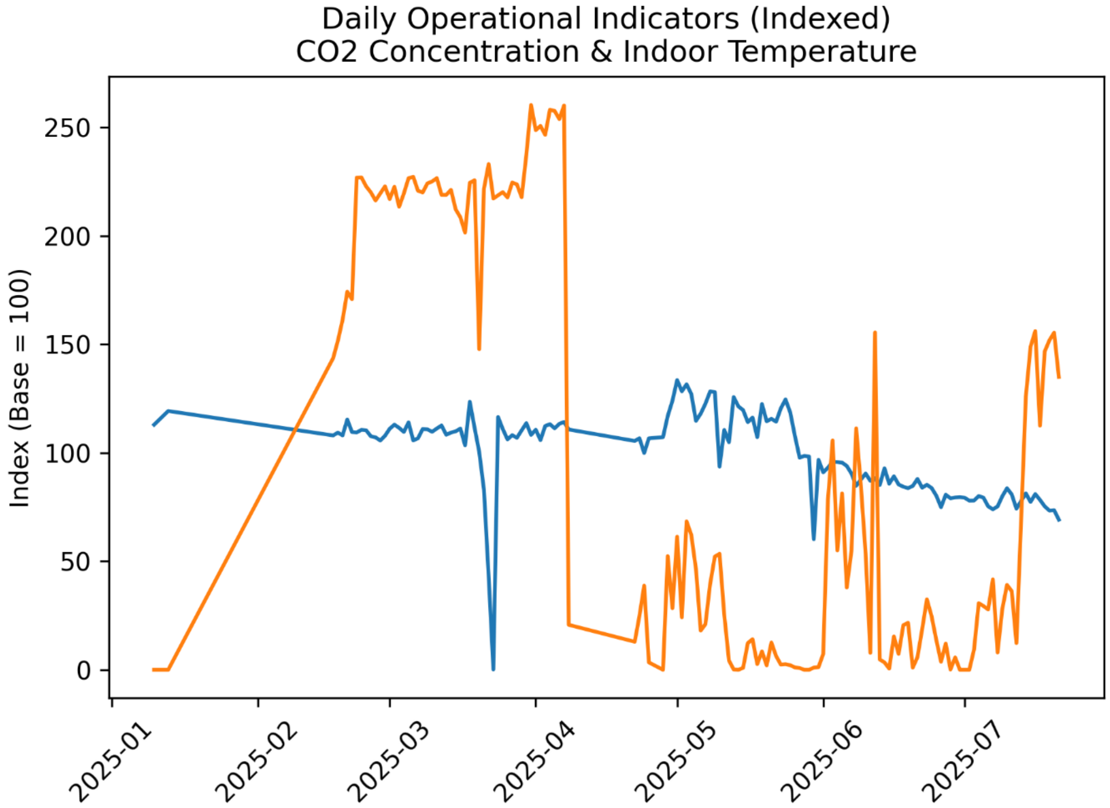


Figure 4: Daily Operational Indicators (orange CO2??, blue indoor temperature??)

The figure presents the daily evolution of operational indoor indicators based on fully anonymised and aggregated data, showing average CO_2 concentration and indoor temperature normalised to an index (base 100) to allow direct comparison. The results illustrate the dynamic interaction between occupancy-driven ventilation patterns and thermal conditions over time, highlighting periods of increased CO_2 levels that may correspond to higher occupancy or reduced air exchange, as well as seasonal variations in indoor temperature. By using indexed values, the graphic enables a clear assessment of relative trends without disclosing sensitive raw data, supporting a transparent and technically robust evaluation of building operational behaviour within the CHRONICLE framework.

IE

O’Cualann Monitoring Analysis

Data Methodology

The impact assessment relies on operational monitoring data collected through the IES platform. Sensors deployed across building zones record time-series measurements that are automatically aggregated into structured datasets. The monitoring system captures high-resolution operational signals associated with building behaviour and environmental conditions. Datasets were consolidated, cleaned, and aggregated to generate annual and monthly indicators describing monitoring coverage and operational patterns.

Monitoring Results

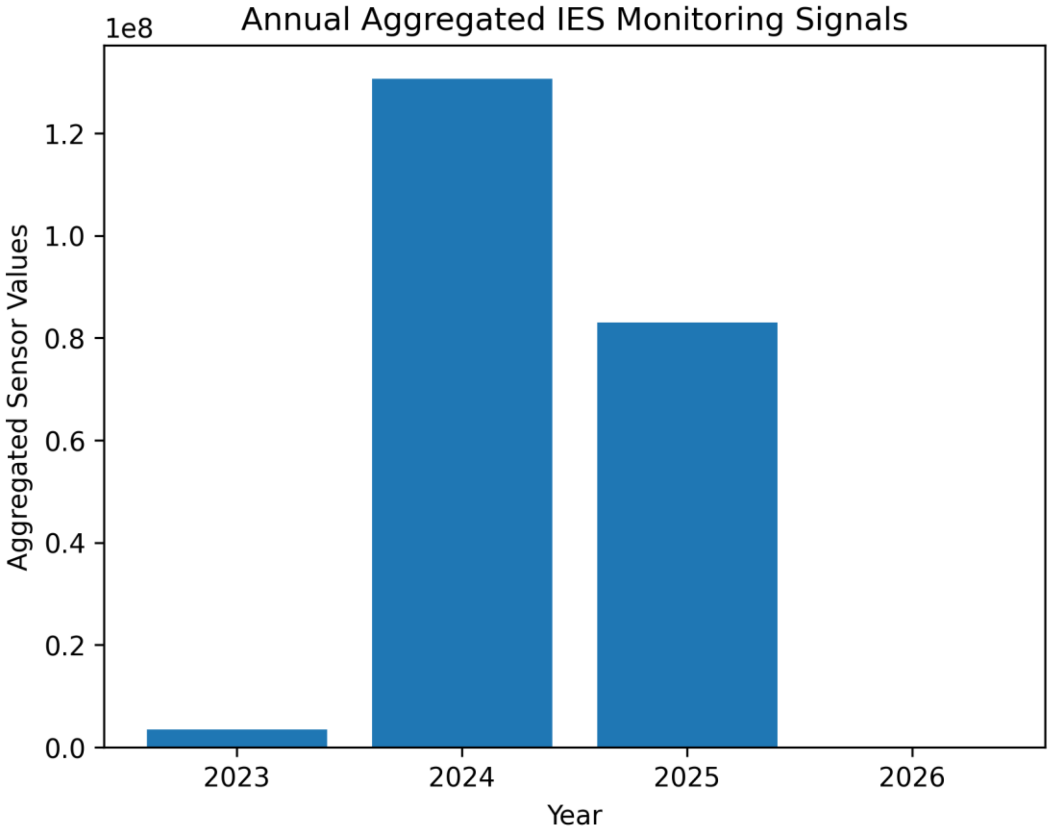


Figure 5: Annual aggregated monitoring signals collected through the IES platform

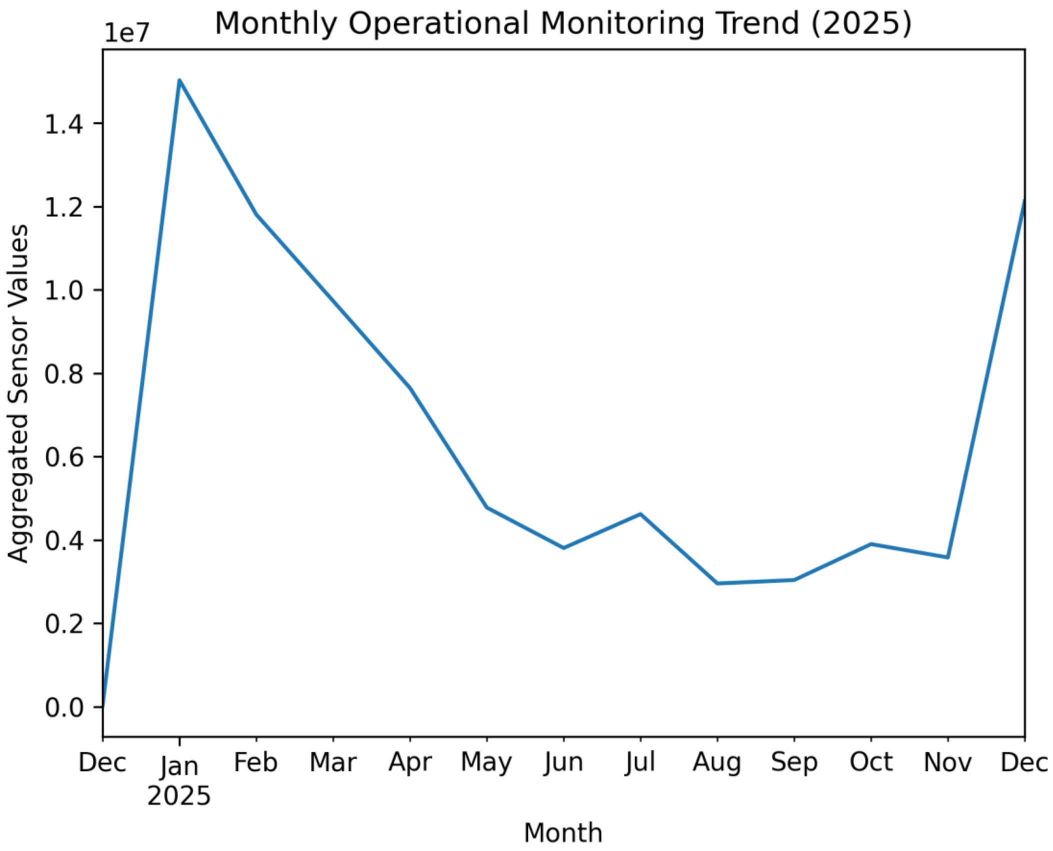


Figure 6: Monthly operational monitoring trend for 2025.

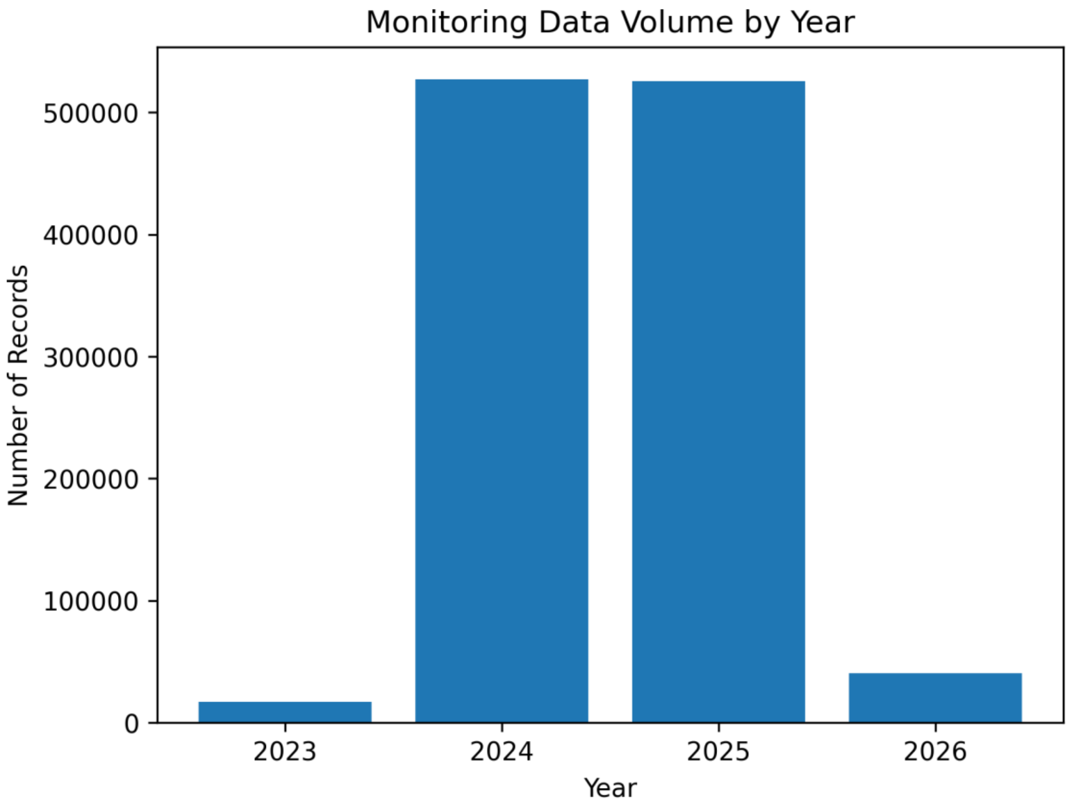


Figure 7: Monitoring data volume by year (number of records).

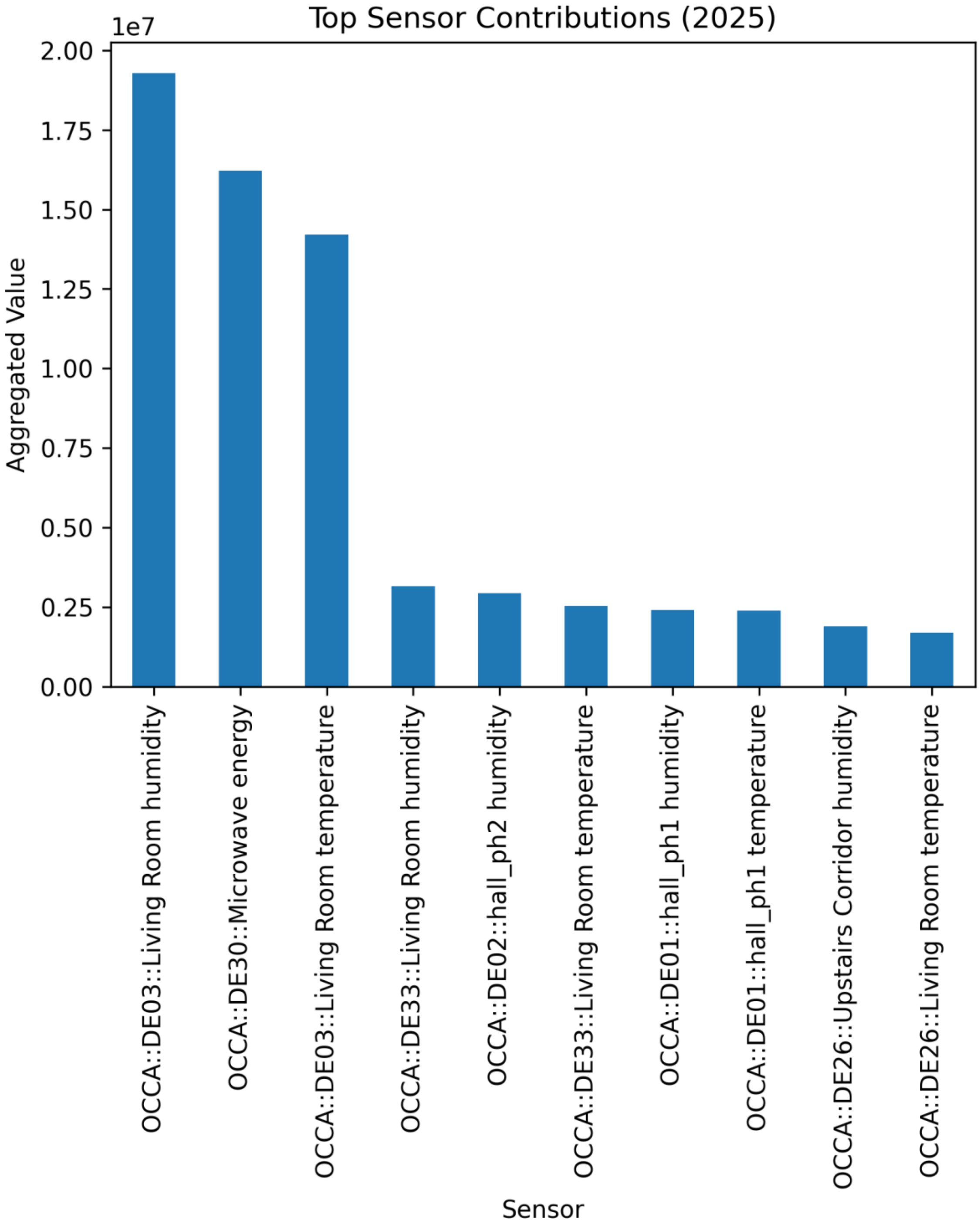


Figure 8: Distribution of the most active sensors contributing to monitoring signals in 2025.

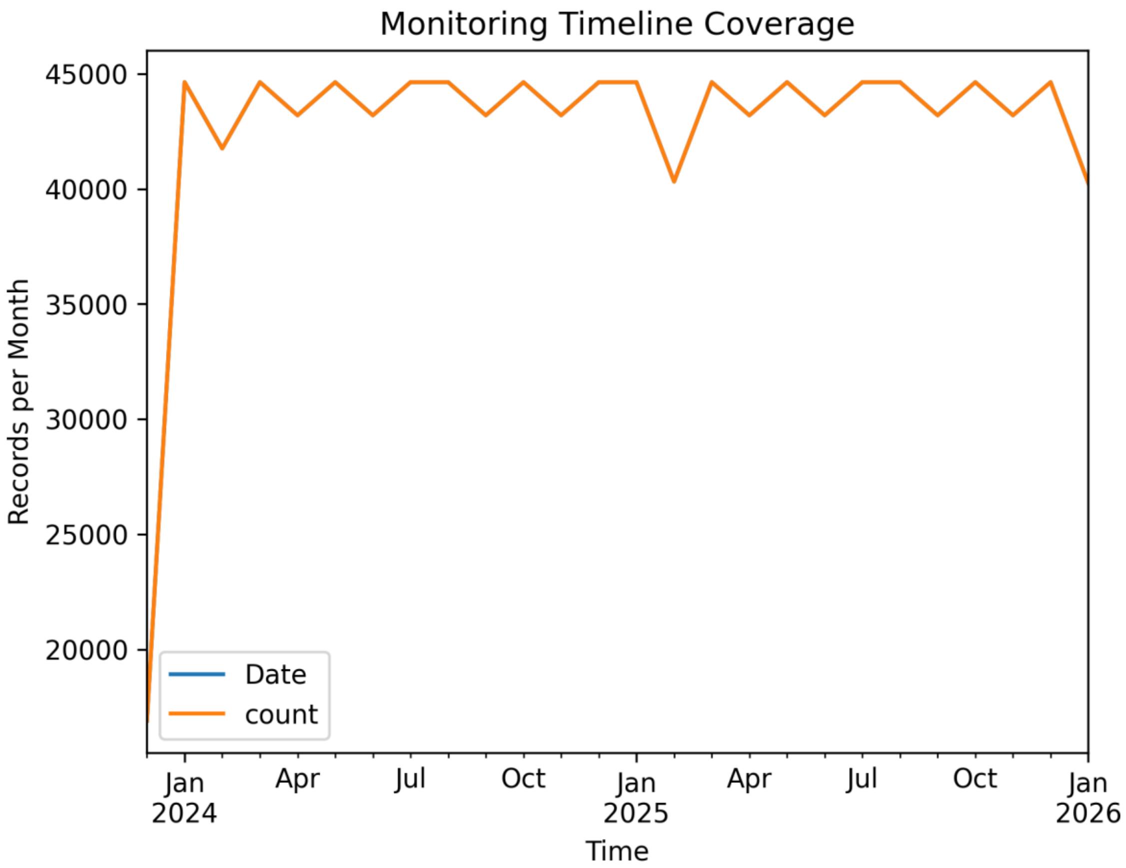


Figure 9: Timeline of monitoring data coverage

8.9 Annex III Risk Analysis for Renovation Measures

The risk analysis is essential to identify the optimal interventions. Indeed, the selection of a specific intervention must consider also the risks associated with its application. The approach proposed in this section considers two categories of risks:

- Technical
- Economic

The calculation of risks in both cases was conducted by creating a 3x3 risk matrix where the probability of a risk and its severity were defined on a scale from one to three. The probability that a risk occurs is classified from 1 up to 3 where:

1. Low probability
2. Medium probability
3. High probability

At the same time, the severity of a risk is identified as:

1. Low severity. The intervention could lead to low risks, therefore the occurrence of this risk is manageable and somehow acceptable
2. Medium severity. The associated intervention could cause a significant risk (technical and economic). The occurrence of this risk should be properly foreseen and avoided with proper mitigation plans.
3. High severity. This severity class implies that the associated interventions could lead to alarming risks. These risks could significantly compromise the technical or economic feasibility of the intervention. Therefore, proper considerations and mitigation plans must be carried out before implementation.

By multiplying the two values, it is possible to find the corresponding risk index. Based on the obtained risk values, using a colour scale, it is possible to identify the risks that require greater attention and/or immediate intervention:

- Green: the risk has a low impact and can therefore be neglected in the selection of the associated intervention.
- Yellow: the identified risk has a medium impact and should therefore be taken into proper consideration. A mitigation plan should be considered.
- Red: the identified risk has a high impact. The associated intervention could be discarded or detailed mitigation plans should be prioritized.

Table 28: Risk Index

		Severity		
		1	2	3
Probability	1	1	2	3
	2	2	4	6
	3	3	6	9

Given the variety of interventions planned in the five pilot sites, the risks have been divided into four macro-categories to simplify the understanding and the process. The categories are, in some cases, interconnected:

- Risks related to materials.
- Risks related to the building envelope.
    - For walls: the total risk comes from the sum of material and typology of intervention risks.
    - For windows: the total risk comes from the sum of material, typology of intervention and glass treatment risks.
- Risks related to the Mechanical, Electrical, and Plumbing components (MEP).
- Risks related to the Distributed Energy Resources components (DER).

Each category includes the corresponding types of interventions, dividing the risks into technical and economic. For each type of intervention, up to ten risks were identified, including five related to technical risks and five related to economic risks. To have a comprehensive view of the risks and compare them with each other, the "percentage risk score" is introduced as:

- Technical percentage risk score: defined as the ratio between the technical risk value of the individual intervention and the maximum possible technical risk.
- Economic percentage risk score: defined as the ratio between the economic risk value of the individual intervention and the maximum possible economic risk.
- Total percentage risk score: defined as the ratio between the sum of the technical and economic risks of the individual intervention and the maximum possible total risk.

To have a more detailed analysis it is necessary to introduce a specific nomenclature for the different types of interventions. In the following table there are all the feasible interventions with their specific code:

Table 29: List of feasible interventions.

Code	Category	Description
E1	Envelope	Adding or increasing external insulation to the walls using EPS rigid sheets
E2	Envelope	Adding insulation to the walls using Mineral or Rock Wool
E3	Envelope	Adding insulation to the walls using Insulating Mortar or Concrete
E4	Envelope	Adding or increasing internal insulation in walls using Mineral or Rock Wool
E5	Envelope	Adding or increasing internal insulation in walls using EPS rigid sheets
E6	Envelope	Adding or increasing internal insulation in walls using Polyurethane Foam Spray
E7	Envelope	Adding insulation in air chambers of walls through injection
E8	Envelope	Adding or increasing external insulation in floors using EPS rigid sheets
E9	Envelope	Adding or increasing external insulation in floors using Polyurethane Foam Spray
E10	Envelope	Adding or increasing external insulation in floors using Mineral or Rock Wool
E11	Envelope	Adding or increasing external insulation in floors using Insulating Mortar or Concrete
E12	Envelope	Use of appropriate materials to increase the thermal inertia of the exposed surfaces to solar radiation
E13	Envelope	Application of an appropriate solar reflectance coating for the external walls
E14	Envelope	Application of an appropriate solar reflectance coating for the internal walls
E15	Envelope	Adding or increasing external insulation in roofs using Mineral or Rock Wool
E16	Envelope	Adding or increasing external insulation in roofs using EPS rigid sheets
E17	Envelope	Application of an appropriate solar reflectance coating for the roof
E18	Envelope	Adding or increasing internal insulation in floors using Insulating Mortar or Concrete
E19	Envelope	Adding or increasing internal insulation in floors using Mineral or Rock Wool
E20	Envelope	Adding or increasing internal insulation in floors using Polyurethane Foam Spray
E21	Envelope	Adding or increasing internal insulation in floors using EPS rigid sheets
W1	Windows	Installation of efficient windows (double glazing with aluminum frames with thermal break)
W2	Windows	Installation of efficient windows (double glazing with wood frames)
W3	Windows	Installation of efficient windows (double glazing with PVC frames)
W4	Windows	Installation of efficient windows (low-E double glazing with aluminum frames with thermal break)
W5	Windows	Installation of efficient windows (low-E double glazing with wood frames)
W6	Windows	Installation of efficient windows (low-E double glazing with PVC frames)
W7	Windows	Installation of efficient windows (solar control double glazing with aluminum frames with thermal break)
W8	Windows	Installation of efficient windows (solar control double glazing with wood frames)
W9	Windows	Installation of efficient windows (solar control double glazing with PVC frames)
W10	Windows	Installation of efficient windows (triple glazing with aluminum frames with thermal break)
W11	Windows	Installation of efficient windows (triple glazing with wood frames)
W12	Windows	Installation of efficient windows (triple glazing with PVC frames)
W13	Windows	Installation of double windows
MEP1	HVAC	Installation of a condensing boiler
MEP2	HVAC	Installation of a heat recovery system in the ventilation air
MEP3	HVAC	Installation of Variable Frequency Drives (VFDs) on motors
MEP4	HVAC	Installation of high efficient motors for fans and pumps
MEP5	HVAC	Replace V-belts with cogged or synchronous belt drives
MEP6	HVAC	Replacement of electric radiators or unit heaters by heat pumps
MEP7	HVAC	Installation of aero-thermal energy
MEP8	HVAC	Installation of a CO2 heat pump
MEP9	HVAC	Installation of Drain Water Heat Recovery (DWHR) systems
DER1	Renewable Energy Sources	Installation of solar thermal panels
DER2	Renewable Energy Sources	Installation of photovoltaic panels

Material risks analysis

The technical risks associated with the materials are reported in the table below with the respective descriptions.

Table 30: Technical material risks

		Technical Risks																
		Risk 1 description	**Probability Risk 1**	**Gravity Risk 1**	**Risk 1**	**Risk 2 description**	**Probability Risk 2**	**Gravity Risk 2**	**Risk 2**	**Risk 3 description**	**Probability Risk 3**	**Gravity Risk 3**	**Risk 3**	**Risk 4 description**	**Probability Risk 4**	**Gravity Risk 4**	**Risk 4**	Total
	Insulation materials																	
A1	*EPS rigid sheets*	Flammable material despite the application of specific flame retardant treatments	3	2	6	Exposure to UV rays can prematurely degrade the material	2	1	2				0				0	8
A2	*Mineral or Rock Wool*	To comply with local regulations, high thicknesses may be required (not very high-performance material)	2	2	4	It can be a preferential way for the passage of smoke in the event of a fire emergency	1	3	3				0				0	7
A3	*Mortar or Concrete*	To comply with local regulations, high thicknesses may be required (not very high-performance material)	2	2	4	Substantial increase in the weight of the structure despite a modest improvement in thermal behaviour	3	3	9				0				0	13
A4	*Polyurethane Foam Spray*	Flammable material despite the application of specific flame retardant treatments	3	2	6	Incorrect application may result in poor performance. Skilled labor is generally required.	2	2	4	The substances in the spray are potentially irritating if not applied correctly. Some people may be more sensitive to these substances.	1	2	2	The substances in the spray could cause permanent odors if not applied correctly	1	2	2	14
																		0
	Window materials																	0
A5	*Aluminum frame*	Strong discontinuity of thermal transmittance between frame and wall. Possibility of creating thermal bridges if not correctly installed	3	2	6				0	Ageing	1	2	2	Dependency on maintenance	2	1	2	10
A6	*Wood frame*	Low fire resistance	2	2	4	More maintenance required: humidity and insects can damage them	2	2	4	Ageing	3	2	6	Dependency on maintenance	2	3	6	20
A7	*PVC frame*	Low fire resistance	2	2	4	On average, the useful life is maximum of 30 years	3	1	3	Ageing	2	2	4	Dependency on maintenance	2	1	2	13

The table shows that the choice of insulation material could be associated with important technical risks. The structure, as well as the need for high thickness for compliance with local regulations are the cause of these elevate risks. In addition, the selection of window materials can affect the risk of the intervention as well, in particular regarding the thermal transmittance. The use of wooden frames, even if associated with high aesthetic value and good insulation properties, leads to significant issues in terms of maintenance and ageing.

Table 31: Economic material risks[1]

		Economic Risks												
		Risk 1 description	Probability Risk 1	Gravity Risk 1	Risk 1	Risk 2 description	Probability Risk 2	Gravity Risk 2	Risk 2	Risk 3 description	Probability Risk 3	Gravity Risk 3	Risk 3	Total
	Insulation materials													
A1	*EPS rigid sheets*	Availability of initial financial capital money	2	1	2	Long PBT	3	2	6				0	8
A2	*Mineral or Rock Wool*	Availability of initial financial capital money	1	1	1	Long PBT	1	2	2				0	3
A3	*Mortar or Concrete*	Availability of initial financial capital money	2	1	2	Long PBT	1	2	2				0	4
A4	*Polyurethane Foam Spray*	Availability of initial financial capital money	2	1	2	Long PBT	2	2	4	Skilled labor could increase costs	1	2	2	8
														0
	Window materials													0
A5	*Aluminum frame*	Availability of initial financial capital money	1	1	1				0	High initial cost	2	2	4	5
A6	*Wood frame*	Availability of initial financial capital money	2	1	2	The lower resistance may require replacing some components more often, with an increase in costs	1	1	1	High initial cost	2	2	4	7
A7	*PVC frame*	Availability of initial financial capital money	2	1	2	The lower resistance may require replacing some components more often, with an increase in costs	1	1	1				0	3
														0

The economic risks related to materials are limited, considering that it represents an advanced solution. The payback time in some cases (e.g. EPS rigid sheets, Polyurethane foam spray) should be properly checked with a more detailed analysis of costs and benefits to avoid bad investments.

Envelope risks analysis

The primary risks associated with interventions on the building envelope are largely related to compliance with local regulations concerning aesthetic requirements. Implementing external interventions would thus require additional effort to meet or maintain these standards. Conversely, focusing on interior modifications, particularly for insulation, carries the risk of reducing usable space, especially if low-performance insulation materials are used, necessitating thicker layers. Another critical consideration, particularly in the case of apartment buildings, is the need to reach a consensus among tenants regarding the intervention (especially for external insulation), which could result in added costs, delays, and suboptimal solutions.

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[1] Source: https://www.sciencedirect.com/science/article/pii/S2214509521001972

Table 32: Technical envelope risks

		Technical Risks																				
		Risk 1 description	**Probability Risk 1**	**Gravity Risk 1**	**Risk 1**	**Risk 2 description**	**Probability Risk 2**	**Gravity Risk 2**	**Risk 2**	**Risk 3 description**	**Probability Risk 3**	**Gravity Risk 3**	**Risk 3**	**Risk 4 description**	**Probability Risk 4**	**Gravity Risk 4**	**Risk 4**	**Risk 5 description**	**Probability Risk 5**	**Gravity Risk 5**	**Risk 5**	**Total**
	Insulation																					
B1	*Internal insulation*	Generally less effective, reduces available space. Invasive intervention, requires emptying the room	3	1	3	The furniture may no longer be compatible with the new internal measurements	2	1	2	It can introduce condensation problems, which must be carefully evaluated	2	2	4									9
B2	*External insulation*	Facade restrictions by local regulations, invasive interventions	2	3	6	Increased building footprint	3	1	3	It can introduce condensation problems, which must be carefully evaluated	2	2	4	For flat apartments need of involving acceptance from all the owners.	3	2	6	The structural load for horizontal walls must be under control, therefore lighter insulators could be needed with a cost increase	2	2	4	23
																						0
	Reflective treatment																					0
B3	*Internal treatment*	Interior reflective treatments may be less effective at reducing heat than exterior reflective treatments, as they do not block solar radiation before it enters the building.	2	2	4	Compatibility issues	1	1	1								0				0	5
B4	*External treatment*	Facade restrictions by local regulations	2	3	6	For flat apartments need of involving acceptance from all the owners.	3	2	6								0				0	12
																						0
B5	**Windows**	Facade restrictions by local regulations, invasive interventions	2	3	6	The window must be aligned with the performance of the envelope, otherwise thermal bridges and consequent discomfort will be generated.	2	2	4	Compliance with aesthetic local regulations, especially for heritage building and historical center	3	2	6	It can introduce condensation problems, which must be carefully evaluated	2	2	4	The geometry of the windows must respect regulations about natural light	1	1	1	21
B6	Low-E glass	In summer the rooms could be subject to overheating	2	2	4				0													4
B7	Solar control glass	Selective glass decreases solar gain: in summer it is an advantage, in winter it is a disadvantage. Not recommended for cold climates. It can increase consumption and therefore PBP (example: Ireland). Vice versa for hot climates (example: Greece)	2	2	4	Reduces incoming light	1	1	1													5

Table 33: Economic envelope risks

		Economic Risks												
		Risk 1 description	Probability Risk 1	Gravity Risk 1	Risk 1	Risk 2 description	Probability Risk 2	Gravity Risk 2	Risk 2	Risk 3 description	Probability Risk 3	Gravity Risk 3	Risk 3	Total
	Insulation													
B1	*Internal insulation*	Choice of materials influences insulation thicknesses and costs for the same useful effect	2	2	4	Risk of increasing intervention costs	1	1	1					5
B2	*External insulation*	Choice of materials influences insulation thicknesses and costs for the same useful effect	2	2	4	Risk of increasing intervention costs	3	1	3					7
														0
	Reflective treatment													0
B3	*Internal treatment*													0
B4	*External treatment*													0
														0
B5	**Windows**	The disposal of old windows must be taken into account in the design phase	2	1	2				0				0	2
B6	Low-E glass	High cost and dependency on local climate for PBT	2	2	4	In summer costs for cooling can increase due to overheating	2	1	2				0	6
B7	Solar control glass	High cost and dependency on local climate for PBT	2	2	4	In winter costs for heating can increase due to the decrease of solar gain	2	1	2	The reduction of incoming light can increase costs related to artificial light	1	1	1	7

For envelope interventions, the economic risks are generally less significant. However, it is highly recommended to conduct a thorough analysis of the local climate to accurately assess the requirements and optimize the selection of appropriate interventions.

MEP risk analysis

The key factor to consider is the system's compatibility with local climate conditions and its resilience to anticipated climate changes. A thorough assessment of long-term performance and potential degradation is essential. Significant risks typically arise when there is a major technological shift. Conversely, adopting an electrified energy system enhances resilience by reducing dependency on fossil fuels and natural gas. Regarding electrical and plumbing systems, relatively few risks are identified, making these interventions generally secure, though they tend to offer only minor improvements.

Table 34: Technical MEP risks

		Technical Risks																
		Risk 1 description	**Probability Risk 1**	**Gravity Risk 1**	**Risk 1**	**Risk 2 description**	**Probability Risk 2**	**Gravity Risk 2**	**Risk 2**	**Risk 3 description**	**Probability Risk 3**	**Gravity Risk 3**	**Risk 3**	**Risk 4 description**	**Probability Risk 4**	**Gravity Risk 4**	**Risk 4**	**Total**
	Mechanical																	
C1	*Installation of a condensing boiler*	Compared to traditional boilers, more maintenance is required	3	1	3	Gas dependency could represent a limitation in the future considering the conversion towards electric system (HPs)	2	2	4	Performance depending on the typologies of emitters	2	2	4					11
C2	*Installation of a heat recovery system in the ventilation air*	The available space may not be sufficient to install the recuperator	2	3	6	If the external and internal temperatures are very similar, the useful effect of the recuperator is negligible.	2	2	4				0					10
C3	*Replace V-belts with cogged or synchronous belt drives*	Compatibility issues	2	2	4				0				0					4
C4	*Replacement of electric radiators or unit heaters by heat pumps*	Without storage the system would not be able to provide DHW instantly.	3	2	6	External unit, if present, can have an impact to the facade	2	2	4	Without the correct sizing, internal comfort could be affected.	2	2	4	Possible need of increasing the electicity supply capacity (standard use 3kW could not be enough)	2	1	2	16
C5	*Installation of aero-thermal energy*	Sensitivity to outdoor temperature could cause drop of performance in the future considering the climate change impact	3	2	6				0				0					6
C6	*Installation of a CO2 heat pump*	In hot climates the performance of CO2 HPs can drop significantly	2	1	2	Using CO2 as a refrigerant requires advanced technology and specific design (high pressure). Not all technicians are trained to work with these systems, which can limit the availability of technical support.	3	1	3	CO2 heat pumps can be bigger than traditional HP, thus requiring more space for installation.	2	2	4	High pressure could represent a safety risk for domestic indoor installations	2	2	4	13
																		0
	Electrical																	0
C7	*Installation of Variable Frequency Drives (VFDs) on motors*	Additional component could cause disfunctioning more often	1	1	1													1
C8	*Installation of high efficient motors for fans and pumps*	No particular controindications																0
																		0
	Plumbing																	0
C9	*Installation of Drain Water Heat Recovery (DWHR) systems*	PBT strongly depend on the use of the system (for sporadic lived apartment could be not convenient)	1	2	2	Availabaility of Expert plumbers for the installation	2	1	2	Available space in the present plumbing system for the installation of the additional components	1	3	3					7

For what concerns the economic considerations, the more innovative the system is, the more economic risk is present. The higher costs can be partially balanced by a lower payback period due to better performance of the system. To reduce these costs, it is fundamental to properly develop a techno-economic assessment to optimize the size and performance of the implemented solutions. Certainly, the possible future fluctuations of energy prices could affect this analysis. Therefore, proper consideration of the uncertainties related to these prices must be carried out as well.

Table 35: Economic MEP risks

		Economic Risks								
		Risk 1 description	**Probability Risk 1**	**Gravity Risk 1**	**Risk 1**	**Risk 2 description**	**Probability Risk 2**	**Gravity Risk 2**	**Risk 2**	**Total**
	Mechanical									
C1	*Installation of a condensing boiler*	Increase in gas costs can increase the PBP	2	2	4	Improper and inadequate maintenance may require frequent component replacement, resulting in increased operating costs.	1	2	2	6
C2	*Installation of a heat recovery system in the ventilation air*								0	0
C3	*Replace V-belts with cogged or synchronous belt drives*								0	0
C4	*Replacement of electric radiators or unit heaters by heat pumps*	High CAPEX. Important to properly design the HP with correct size, depending on the outdoor temperature. In the future, higher outdoor temperature will decrease the HPs' efficiency	3	2	6	Increase in electricity costs can increase the PBP	2	1	2	8
C5	*Installation of aero-thermal energy*				0				0	0
C6	*Installation of a CO2 heat pump*	High CAPEX. Important to properly design the HP with correct size, depending on the outdoor temperature. In the future, higher outdoor temperature will decrease the HPs' efficiency	3	2	6	Increase in electricity costs can increase the PBP	2	1	2	8
										0
	Electrical									0
C7	*Installation of Variable Frequency Drives (VFDs) on motors*									0
C8	*Installation of high efficient motors for fans and pumps*									0
										0
	Plumbing									0
C9	*Installation of Drain Water Heat Recovery (DWHR) systems*	Accurate Assessment must be carried out depending on the local use of water in order to verify the economic feasibility of the intervention	3	2	6					6

DER risk analysis

For Distributed Energy Resources (DER), the risk landscape is highly diverse. Numerous risks, both technical and economic, have been identified. These risks must be carefully assessed; however, it is important to note that these technologies offer numerous advantages that can significantly influence the decision to implement them. Indeed, the technologies discussed are now well-established and widely adopted. Typically, the major risks are associated with historical constraints and the proper installation of technologies (both in terms of positioning and energy coupling). Proper analysis of local energy demand must be carried out to ensure proper sizing of the technology that guarantees maximization of self-consumption and consequent economic benefits.

Table 36: Technical DER risks

		Technical Risks																				
		Risk 1 description	Probability Risk 1	Gravity Risk 1	Risk 1	Risk 2 description	Probability Risk 2	Gravity Risk 2	Risk 2	Risk 3 description	Probability Risk 3	Gravity Risk 3	Risk 3	Risk 4 description	Probability Risk 4	Gravity Risk 4	Risk 4	Risk 5 description	Probability Risk 5	Gravity Risk 5	Risk 5	Total
	DER																					
D1	PV panels	Reduction in production due to dirt or damage (extreme weather conditions).	2	2	4	Efficiency reduction over time	3	1	3	When installed in historical center or heritage building there could be problem due to the aesthetic local code	2	3	6	Structural capacity of the roof must be compliant with the additional panels weight	1	3	3	Production and demand coupling problem. Without storage there is a risk that the energy produced will not be used. With storage costs increase. PBP increases	3	2	6	22
D2	Solar Thermal panels	Reduction in production due to dirt or damage (extreme weather conditions).	2	2	4	Efficiency reduction over time	3	1	3	When installed in historical center or heritage building there could be problem due to the aesthetic local code	2	3	6	Structural capacity of the roof must be compliant with the additional panels weight	1	3	3	Production and demand coupling problem. Without storage there is a risk that the energy produced will not be used. With storage costs increase. PBP increases	3	2	6	22

From the economic point of view, the main risks are mainly due to bad technical decisions that lead to lower exploitation of technology and, therefore, lower revenues. The impact on the building structure could be relevant in the case of solar thermal panels. In this specific case, additional costs could be needed to develop renovation work on the roof structure to properly support the load of the new technology.

Table 37: Economic DER risks

		Economic Risks																
		Risk 1 description	Probability Risk 1	Gravity Risk 1	Risk 1	Risk 2 description	Probability Risk 2	Gravity Risk 2	Risk 2	Risk 3 description	Probability Risk 3	Gravity Risk 3	Risk 3	Risk 4 description	Probability Risk 4	Gravity Risk 4	Risk 4	Total
	DER																	
D1	PV panels	Energy cost reduction increase PBP	2	1	2	Reduced production due to incorrect installation (orientation, shading, etc.) could increase PBP	2	3	6	Additional costs for Balance of plant	2	1	2	Risk for cost related to strucutural reinforcement	1	3	3	13
D2	Solar Thermal panels	Energy cost reduction increase PBP	2	1	2	Reduced production due to incorrect installation (orientation, shading, etc.) could increase PBP	2	3	6	Additional costs for Balance of plant	2	1	2	Risk for cost related to strucutural reinforcement	2	3	6	16

Demosite application

In the following sections, the analysis carried out specifically on the interventions foreseen in the demo sites will be reported. This analysis would help select the best interventions, taking into consideration the associated risks.

SPAIN

The technically feasible renovation measures in Spain are summarised in the following table and for each renovation measure it is possible to define the percentage risk score:

Table 38: Feasible renovation measures Spain

Code	Categories	Description	Associated risk category
E4	Envelope	Adding or increasing internal insulation in walls using Mineral or Rock Wool	A2, B1
E15	Envelope	Adding or increasing external insulation in roofs using Mineral or Rock Wool	A2, B2
E16	Envelope	Adding or increasing external insulation in roofs using EPS rigid sheets	A1, B2
E19	Envelope	Adding or increasing internal insulation in floors using Mineral or Rock Wool	A2, B1
W4	Windows	Installation of efficient windows (low-E double glazing with aluminium frames with thermal break)	A5, B5, B6
MEP1	HVAC	Installation of a condensing boiler	C1
MEP7	HVAC	Installation of aero-thermal energy	C5

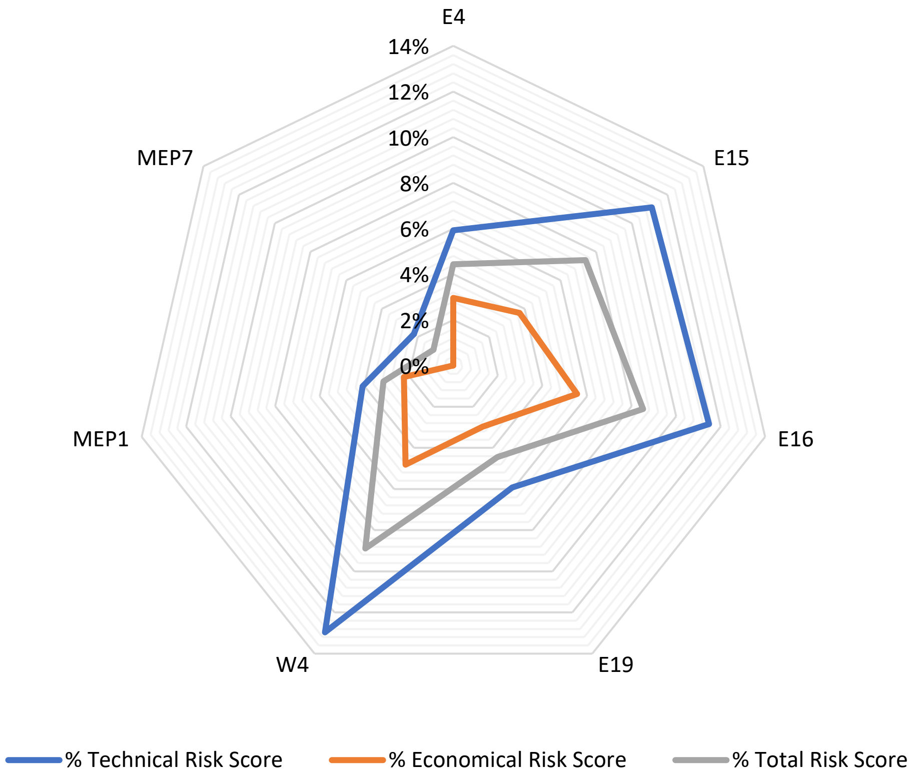

Figure 10: Risk score rosette Spain

In Spain, the renovation measures E15, E16, and W4 are the riskiest in terms of technical and economic risk. The two MEP solutions that are considered can increase the efficiency of the facility with a relatively low risk and the solution E19 should be seriously considered. E19 is the best envelope solution in terms of risk for this building.

DENMARK

The technically feasible renovation measures in Denmark are summarised in the following table and for each renovation measure is possible to define the percentage risk score:

Table 39: Feasible renovation measures Denmark

Code	Categories	Description	Associated risk category
E1	Envelope	Adding or increasing external insulation to the walls using EPS rigid sheets	A1, B2
E10	Envelope	Adding or increasing external insulation in floors using Mineral or Rock Wool	A2, B2
E15	Envelope	Adding or increasing external insulation in roofs using Mineral or Rock Wool	A2, B2
W1	Windows	Installation of efficient windows (double glazing with aluminium frames with thermal break)	A5, B5
W10	Windows	Installation of efficient windows (triple glazing with aluminium frames with thermal break)	A5, B5
MEP2	HVAC	Installation of a heat recovery system in the ventilation air	C2
MEP3	HVAC	Installation of Variable Frequency Drives (VFDs) on motors	C7
MEP4	HVAC	Installation of highly efficient motors for fans and pumps	C8
DER2	Renewable Energy Sources	Installation of photovoltaic panels	D1

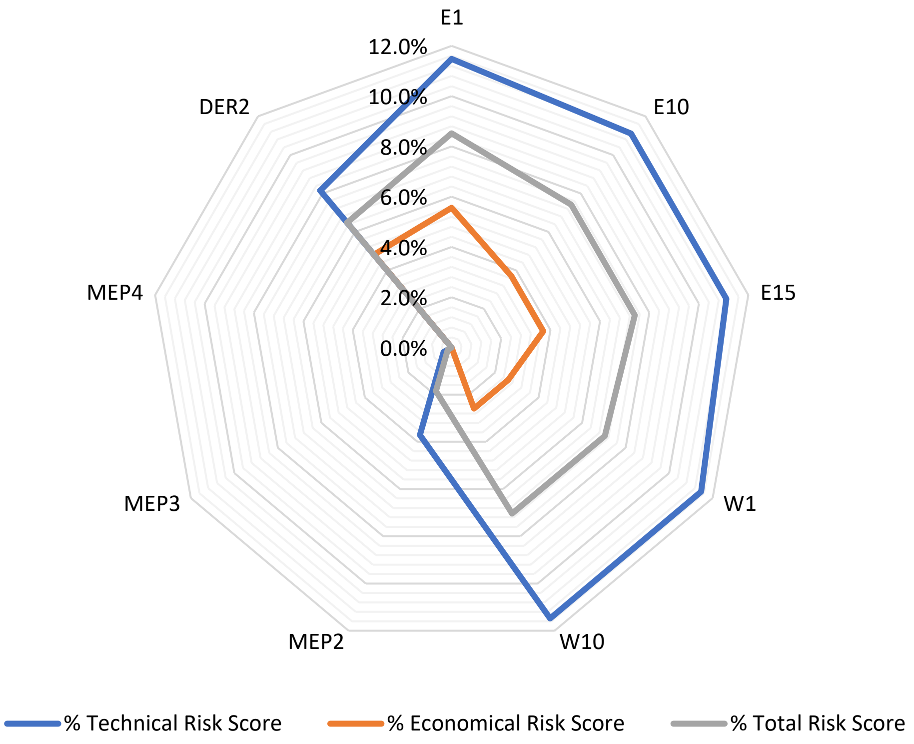

Figure 11: Risk score rosette Denmark

In Denmark, all the Envelope strategies have a high risk in the application, while the MEP strategies are considered with negligible risks. For solutions MEP3 and MEP4 the reduction of energy consumption could be not so impactful. DER2 intervention should be carefully considered, particularly concerning building heritage.

IRELAND

The technically feasible renovation measures in Ireland are summarised in the following table and for each renovation measure is possible to define the percentage risk score:

Table 40: Feasible renovation measures Ireland

Code	Categories	Description	Associated risk category
E1	Envelope	Adding or increasing external insulation to the walls using EPS rigid sheets	B2, A1
E4	Envelope	Adding or increasing internal insulation in walls using Mineral or Rock Wool	B1, A2
E5	Envelope	Adding or increasing internal insulation in walls using EPS rigid sheets	B1, A1
E6	Envelope	Adding or increasing internal insulation in walls using Polyurethane Foam Spray	B1, A4
E7	Envelope	Adding insulation in air chambers of walls through injection	B1, A4
E15	Envelope	Adding or increasing external insulation in roofs using Mineral or Rock Wool	B2, A2
E16	Envelope	Adding or increasing external insulation in roofs using EPS rigid sheets	B2, A1
W1	Windows	Installation of efficient windows (double glazing with aluminium frames with thermal break)	B5, A5
W2	Windows	Installation of efficient windows (double glazing with wood frames)	B5, A6
W3	Windows	Installation of efficient windows (double glazing with PVC frames)	B5, A7
W4	Windows	Installation of efficient windows (low-E double glazing with aluminium frames with thermal break)	B5, A5, B6
W5	Windows	Installation of efficient windows (low-E double glazing with wood frames)	B5, A6, B6
W6	Windows	Installation of efficient windows (low-E double glazing with PVC frames)	B5, A7, B6
W7	Windows	Installation of efficient windows (solar control double glazing with aluminum frames with thermal break)	B5, A5, B7
W8	Windows	Installation of efficient windows (solar control double glazing with wood frames)	B5, A6, B7
W9	Windows	Installation of efficient windows (solar control double glazing with PVC frames)	B5, A7, B7
W10	Windows	Installation of efficient windows (triple glazing with aluminum frames with thermal break)	B5, A5
W11	Windows	Installation of efficient windows (triple glazing with wood frames)	B5, A6
W12	Windows	Installation of efficient windows (triple glazing with PVC frames)	B5, A7
MEP1	HVAC	Installation of a condensing boiler	C1

MEP2	HVAC	Installation of a heat recovery system in the ventilation air	C2
MEP4	HVAC	Installation of highly efficient motors for fans and pumps	C8
MEP6	HVAC	Replacement of electric radiators or unit heaters by heat pumps	C4
DER1	Renewable Energy Sources	Installation of solar thermal panels	D2
DER2	Renewable Energy Sources	Installation of photovoltaic panels	D1

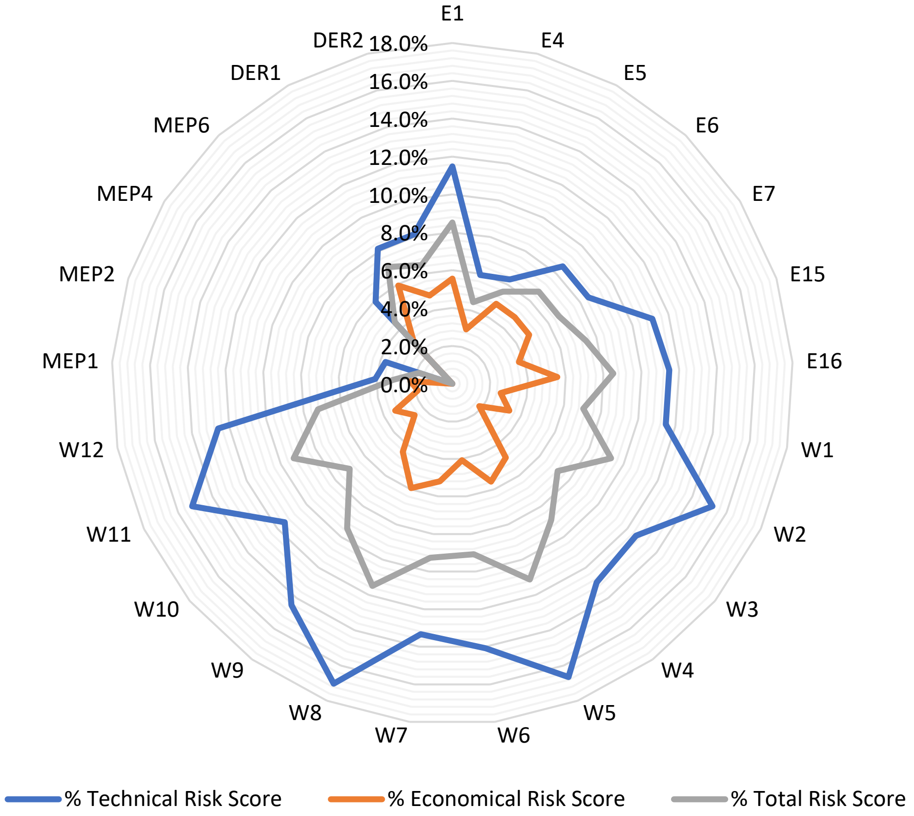

Figure 12: Risk score rosette Ireland

In Ireland, all the Windows strategies have a higher risk in the application, while the MEP strategies are considered with negligible risks. The windows strategies suggested are W1, W3, W4, W7, W10. The materials with the lower risks are Aluminium and PVC, but it is necessary to consider if the material can correctly fit with the building design. In Ireland, solar control is not very useful due to low solar irradiation and mild climate, so the W7 solution should be discarded. For the envelope, E4 and E5 are the better choices in terms of risks but should be carefully considered.

SWITZERLAND

The technically feasible renovation measures in Switzerland are summarised in the following table and for each renovation measure is possible to define the percentage risk score:

Table 41: Feasible renovation measures Switzerland

Code	Category	Description	Associated risk category
E1	Envelope	Adding or increasing external insulation to the walls using EPS rigid sheets	B2, A1
E4	Envelope	Adding or increasing internal insulation in walls using Mineral or Rock Wool	B1, A2
E5	Envelope	Adding or increasing internal insulation in walls using EPS rigid sheets	B1, A1
E6	Envelope	Adding or increasing internal insulation in walls using Polyurethane Foam Spray	B1, A4
E7	Envelope	Adding insulation in air chambers of walls through injection	B1, A4
E8	Envelope	Adding or increasing external insulation in floors using EPS rigid sheets	B2, A1
E9	Envelope	Adding or increasing external insulation in floors using Polyurethane Foam Spray	B2, A4
E10	Envelope	Adding or increasing external insulation in floors using Mineral or Rock Wool	B2, A2
E11	Envelope	Adding or increasing external insulation in floors using Insulating Mortar or Concrete	B2, A3
E13	Envelope	Application of an appropriate solar reflectance coating for the external walls	B4
E14	Envelope	Application of an appropriate solar reflectance coating for the internal walls	B3
E18	Envelope	Adding or increasing internal insulation in floors using Insulating Mortar or Concrete	B1, A3
E19	Envelope	Adding or increasing internal insulation in floors using Mineral or Rock Wool	B1, A2
E20	Envelope	Adding or increasing internal insulation in floors using Polyurethane Foam Spray	B1, A4
E21	Envelope	Adding or increasing internal insulation in floors using EPS rigid sheets	B1, A1
W1	Windows	Installation of efficient windows (double glazing with aluminium frames with thermal break)	B5, A5
W2	Windows	Installation of efficient windows (double glazing with wood frames)	B5, A6
W3	Windows	Installation of efficient windows (double glazing with PVC frames)	B5, A7
W4	Windows	Installation of efficient windows (low-E double glazing with aluminium frames with thermal break)	B5, A5, B6
W5	Windows	Installation of efficient windows (low-E double glazing with wood frames)	B5, A6, B6

W6	Windows	Installation of efficient windows (low-E double glazing with PVC frames)	B5, A7, B6
W7	Windows	Installation of efficient windows (solar control double glazing with aluminium frames with thermal break)	B5, A5, B7
W8	Windows	Installation of efficient windows (solar control double glazing with wood frames)	B5, A6, B7
W9	Windows	Installation of efficient windows (solar control double glazing with PVC frames)	B5, A7, B7
W10	Windows	Installation of efficient windows (triple glazing with aluminium frames with thermal break)	B5, A5
W11	Windows	Installation of efficient windows (triple glazing with wood frames)	B5, A6
W12	Windows	Installation of efficient windows (triple glazing with PVC frames)	B5, A7
MEP5	HVAC	Replace V-belts with cogged or synchronous belt drives	C3
MEP7	HVAC	Installation of aero-thermal energy	C5
MEP8	HVAC	Installation of a CO2 heat pump	C6
MEP9	HVAC	Installation of Drain Water Heat Recovery (DWHR) systems	C9

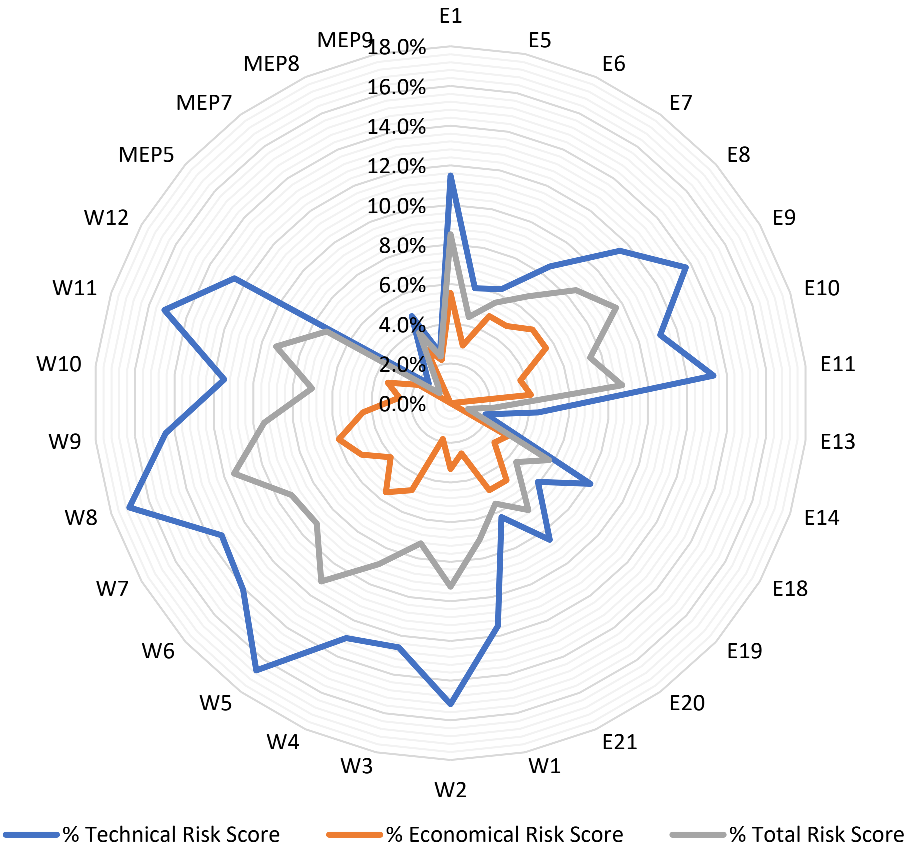

Figure 13:Risk score rosette Switzerland

In Switzerland E9, E11, W2, W5, W8, W11 are the riskiest strategies. The MEP8 represents the solution with the highest risk for the MEP group, but at the same time it is the most innovative and the overall risk is low. The windows strategies have the higher risk in the application, and the windows strategies suggested are W1, W3, W4, W7, W10, and W12. The materials with the lower risks are Aluminium and PVC, but it is necessary to consider if the material can correctly fit with the building design. In Switzerland, solar control is not very useful due to low solar irradiation and mild climate during the summer, so the W7 solution should be discarded. In the envelope group is possible to observe that the solutions E13, and E14 are the ones with the lower risk, due to the simple nature of the intervention. These solutions are not so good in terms of envelope improvement. Again, E5, E6, E19, and E20 are the suggested solutions, principally due to the maturity of the materials adopted.

8.10 Weather database

ERA5 is the fifth generation of the "European Centre for Medium-Range Weather Forecasts" (ECMWF) atmospheric reanalysis of the global climate, and the first reanalysis produced as an operational service. ERA-5 was developed by the Copernicus Climate Change Service (C3S) and replaces the four previous reanalysis FGGE, ERA-15, ERA-40 and ERA-Interim.

ERA5 utilizes the best available observation data from satellites and in-situ stations, which are assimilated and processed using ECMWF's Integrated Forecast System (IFS) Cycle 41r2. In the reanalysis, in addition to the routine measurements, further quality-assured observation data are included (assimilated) in the calculation with the model, which are not included into the routine forecast. These assimilated observational data come from a variety of sources, such as weather stations, radiosonde ascents, ship measurements and, since the 1970s, satellite measurements. The ERA-5 reanalysis period currently begins in 1979 and is continuously updated so that the latest data from approximately 3 months prior to today is available from the ECMWF. ERA-5 uses the same 37 pressure levels as ERA-Interim. The time resolution is 1 to 3 hours depending on the parameter. The reanalysis are not calculated on a Cartesian grid, but on a reduced Gaussian grid with a spatial resolution of 0.250 ~ 25 km for atmospheric parameter values (see Hersbach et al., 2020; ERA5 websites). Frequency is updated at a daily basis with 5 days delay up to today's date.

For our analysis, the environmental parameter of air temperature was used from the reanalysis product of the ERA5 hourly data on single levels from 1940 to present and presented briefly within the following Table 42, i.e.,

Table 42: Hourly parameters description from the ERA5 hourly data on single levels from 1940 to present regridded to a regular lat-lon grid of 0.250 ~ 25 km for the reanalysis

Variable	Units	Description
T2m	K	This parameter is the temperature of air at 2m above the surface of land, sea or inland waters. 2m temperature is calculated by interpolating between the lowest model level and the Earth's surface, taking account of the atmospheric conditions. This parameter has units of kelvin (K). Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.

8.11 Supplementary material of the Human Centric KPI calculations

Aspra Spitia (Apartments)

Table 43: Estimated KPIs of Thermal comfort; Visual comfort; Acoustic comfort; Indoor Air Quality (IAQ) comfort; Well-being comfort and Social comfort for Aspra Spitia (Apartments)

Table. Estimated KPIs of Thermal comfort; Visual comfort; Acoustic comfort; Indoor Air Quality (IAQ) comfort; Well-being comfort and Social comfort for Aspra Spitia (Apartments)

timestamp	CO2	pEUA	PM2.5	pRH	pUI	SPL	TDP	TDRP	TVOC	pAGS	PPS	DD weight	Thermalweighted	Non thermal_mean	mean_score	n_valid	coverage	Penalized_score	rolling_baseline	delta_percent
1/1/2025	0.79	0.00	0.69	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.12	0.12	0.81	0.47	11.00	1.00	0.47	0.47	0.00
2/1/2025	0.78	1.00	0.67	1.00	1.00	0.34	1.00	1.00	1.00	1.00	1.00	0.11	0.11	0.85	0.48	11.00	1.00	0.48	0.47	2.18
3/1/2025	0.77	1.00	0.60	1.00	0.66	0.34	1.00	1.00	1.00	1.00	1.00	0.09	0.09	0.80	0.44	11.00	1.00	0.44	0.48	-7.17
4/1/2025	0.78	1.00	0.61	1.00	1.00	0.34	1.00	1.00	1.00	1.00	1.00	0.04	0.04	0.84	0.44	11.00	1.00	0.44	0.44	-0.03
5/1/2025	0.82	0.00	0.67	1.00	0.65	0.34	1.00	1.00	1.00	1.00	1.00	0.04	0.04	0.68	0.36	11.00	1.00	0.36	0.44	-17.98
6/1/2025	0.86	0.00	0.63	1.00	1.00	0.34	0.00	0.00	1.00	1.00	1.00	0.07	0.02	0.73	0.38	11.00	1.00	0.38	0.36	3.63
7/1/2025	1.00	1.00	0.58	1.00	1.00	0.34	0.00	0.00	1.00	1.00	1.00	0.12	0.04	0.86	0.45	11.00	1.00	0.45	0.38	20.23
8/1/2025	1.00	0.00	0.50	0.00	0.63	0.00	0.00	0.00	1.00	1.00	1.00	0.11	0.00	0.64	0.32	11.00	1.00	0.32	0.45	-29.03
9/1/2025	1.00	NA	0.66	NA	NA	NA	NA	NA	1.00	1.00	1.00	0.06	NA	0.93	0.93	5.00	0.45	0.42	0.32	32.18
10/1/2025	1.00	0.00	0.69	1.00	1.00	0.34	1.00	1.00	1.00	1.00	1.00	0.05	0.05	0.75	0.40	11.00	1.00	0.40	0.42	-4.87
11/1/2025	0.76	0.00	0.77	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.08	0.08	0.82	0.45	11.00	1.00	0.45	0.40	10.87
12/1/2025	0.72	0.00	0.73	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.11	0.11	0.81	0.46	11.00	1.00	0.46	0.45	2.61

Zaragoza-Ecce Homo 8

Table 44: Estimated KPIs of Thermal comfort; Visual comfort; Acoustic comfort; Indoor Air Quality (IAQ) comfort; Well-being comfort and Social comfort for Zaragoza-Ecce Homo 8

Table. Estimated KPIs of Thermal comfort; Visual comfort; Acoustic comfort; Indoor Air Quality (IAQ) comfort; Well-being comfort and Social comfort for Zaragoza-Ecce Homo 8

timestamp	CO2	pEUA	PM2.5	pRH	pUI	SPL	TDP	TDRP	TVOC	pAGS	PPS	DD weight	Thermal weighted	Non thermal_mean	mean_score	n_valid	coverage	Penalized _score	rolling_baseline	delta_percent
1/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.182	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
2/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.158	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
3/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.134	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
4/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.077	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
5/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.034	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
6/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.010	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
7/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.002	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
8/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.005	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
9/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.029	NA	1.000	1.000	2.000	0.182	0.182	0.182	0.000
10/1/2025	1	0.008	NA	NA	NA	NA	1	1	NA	1	1	0.077	0.077	0.752	0.414	6.000	0.545	0.226	0.182	24.296
11/1/2025	1	0	NA	NA	NA	NA	0.672	0.662	NA	1	1	0.125	0.083	0.750	0.417	6.000	0.545	0.227	0.226	0.545
12/1/2025	1	0	NA	NA	NA	NA	0.699	0.695	NA	1	1	0.168	0.117	0.750	0.433	6.000	0.545	0.236	0.227	4.059

LaSosta Massagno

Table 45: Estimated KPIs of Thermal comfort; Visual comfort; Acoustic comfort; Indoor Air Quality (IAQ) comfort; Well-being comfort and Social comfort for LaSosta Massagno

Table. Estimated KPIs of Thermal comfort; Visual comfort; Acoustic comfort; Indoor Air Quality (IAQ) comfort; Well-being comfort and Social comfort for LaSosta Massagno

timestamp	CO2	pEUA	PM2.5	pRH	pUI	SPL	TDP	TDRP	TVOC	pAGS	PPS	DD weight	Thermalweighted	Non thermal_mean	mean_score	n_valid	coverage	Penalized_score	rolling_baseline	delta_percent
1/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.171	NA	1	1	2	0.182	0.182	0.182	0
2/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.148	NA	1	1	2	0.182	0.182	0.182	0
3/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.130	NA	1	1	2	0.182	0.182	0.182	0
4/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.081	NA	1	1	2	0.182	0.182	0.182	0
5/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.036	NA	1	1	2	0.182	0.182	0.182	0
6/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.013	NA	1	1	2	0.182	0.182	0.182	0
7/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.004	NA	1	1	2	0.182	0.182	0.182	0
8/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.007	NA	1	1	2	0.182	0.182	0.182	0
9/1/2025	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	0.031	NA	1	1	2	0.182	0.182	0.182	0
10/1/2025	0.882	1	NA	1	NA	1	1	1	NA	1	1	0.085	0.085	0.976	0.531	8	0.727	0.386	0.182	112.347
11/1/2025	0.896	0	NA	0	NA	1	1	1	NA	1	1	0.135	0.090	0.779	0.434	8	0.727	0.316	0.386	-18.154
12/1/2025	0.889	0	NA	0	NA	1	0	0	NA	1	1	0.157	0	0.778	0.389	8	0.727	0.283	0.316	-10.503

8.12 Standards and Normative References

The methodology of CCI is grounded in international and European standards applicable to residential buildings:

Thermal Comfort

- EN 16798-1:2019
  Energy performance of buildings – Indoor environmental input parameters
- ISO 7730:2005
  Ergonomics of the thermal environment – PMV and PPD indices

Visual Comfort

- ISO 17772-1:2017
  Energy performance of buildings – Indoor environmental quality
- EN 12464-1:2021
  Lighting of indoor workplaces (adapted thresholds for residential spaces)

Acoustic Comfort

- WHO Environmental Noise Guidelines for the European Region (2018)
- ISO 16283 (series) – Field measurement of sound insulation
- National building regulations aligned with EN standards

Indoor air quality Comfort

EN 16798-1:2019 – Energy performance of buildings – Ventilation for buildings – Indoor environmental input parameters
Defines IAQ categories (I–IV) and minimum ventilation rates for residential buildings.

ISO 17772-1:2017 – Energy performance of buildings – Indoor environmental quality – Indoor environmental input parameters
Provides harmonised IAQ parameters supporting thermal, visual, acoustic, and air quality comfort.

ISO 16000 (series) – Indoor air
Specifies methods for measuring indoor air pollutants, including:

- ISO 16000-1: General aspects of sampling strategy
- ISO 16000-6: Volatile Organic Compounds (VOCs)
- ISO 16000-26: Carbon dioxide (CO_2) measurement

WHO Guidelines for Indoor Air Quality (2010, updated 2021)
Defines health-based exposure limits for key indoor pollutants, including CO_2, particulate matter ($PM_{2.5}$, PM_{10}), formaldehyde, and other chemical compounds.

ASHRAE Standard 62.2 – Ventilation and Acceptable Indoor Air Quality in Residential Buildings. Referenced as a complementary guideline for residential ventilation effectiveness and air quality perception.

Additional European standards for building performance and indoor environmental assessment

- ISO 52016-1:2017
  Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures
  ISO 52016-1 explicitly recognizes degree days as a valid method for representing climatic severity and for normalizing building performance indicators across different time periods and locations.
- EN 16798-1:2019
  Energy performance of buildings — Ventilation for buildings — Indoor environmental input parameters for design and assessment of energy performance of buildings
  EN 16798-1 establishes acceptable indoor environmental categories and acknowledges the influence of outdoor climatic conditions on indoor thermal comfort, supporting the use of climate-based correction factors such as HDD and CDD for performance assessment.
- ISO 7730:2005 / EN ISO 7730:2006
  Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using PMV and PPD indices ISO 7730 underlines the dependency of thermal comfort indicators on boundary conditions, including outdoor climate, reinforcing the rationale for seasonal adjustment.
- ISO 17772-1:2017
  Energy performance of buildings — Indoor environmental quality — Part 1: Indoor environmental input parameters for the design and assessment of energy performance of buildings. This standard supports harmonized indoor comfort evaluation and allows climate-normalized assessment methodologies for longitudinal analysis.

The Energy Consumption Awareness Impact KPI is aligned directly or indirectly with the following standards and frameworks:

- ISO 52000-1
  Energy performance of buildings – Overarching EPB assessment.
  Defines the framework for calculating and comparing building energy performance.
- ISO 52010-1
  Energy needs and energy use for heating and cooling.
  Supports consistent calculation of final energy consumption.
- EN 15603 / EPBD (EU Energy Performance of Buildings Directive).
  Basis for energy performance indicators used in EPCs.
- ISO 50001
  Energy management systems.

Provides the conceptual foundation for energy performance monitoring and awareness improvement.

- ASHRAE Standard 90.1 (indirect alignment).
  Reference for minimum energy performance in buildings.

9 References

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