Cost-effective and replicable RES-integrated electrified heating and cooling systems for improved energy efficiency and demand response.

D2.1 – PILOT SITE ASSESSMENT REPORT

WP2, Task 2.1 & Task 2.2

Date

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EXECUTIVE SUMMARY

SEEDS project is an innovative effort towards decarbonization, aiming at enhancing energy efficiency and promoting the electrification of thermal demand in buildings. It brings together a multidisciplinary consortium of Small and Medium-sized Enterprises (SMEs), Large Enterprises (LEs), Research and Technology Organizations (RTOs) and a plethora of stakeholders, taking into account the entire local value chain in the sector of building energy efficiency from across Europe. This includes all stages, from planning and design, through construction, to operation and commissioning.

Leveraging the consortium's extensive expertise in decarbonization solutions, SEEDS focuses on the development, testing, and application of novel strategies for building renovation and smartification, along with the deployment of energy flexibility solutions. The replicable heat pump technologies, in conjunction with renewable energy sources that are designed to reduce the carbon footprint of building thermal demand significantly are one of the key elements of SEEDS. As each building is unique, SEEDS prioritizes the development of scalable, cost-efficient and energy-efficient solutions tailored to specific needs, offering a broad spectrum of optimization methodologies for design and operational efficiency.

SEEDS showcases its groundbreaking solutions through six (6) demonstration sites across Europe, including a replication site (Denmark, Slovenia, Belgium, Hungary and Greece). These sites are strategically selected to represent a wide array of climate zones and construction markets, providing tangible, real-world examples of SEEDS' capabilities up to Technology Readiness Levels 6-8.

The initiative of SEEDS is structured around three core themes: enhancing cost efficiency through advanced optimization techniques, achieving system integration via holistic design and control and ensuring replicability thanks to the modular configurations and adaptable building types. To address these themes effectively, SEEDS has identified seven (7) key focus areas, ranging from iterative design processes and secure data management to system optimization, energy flexibility, replication strategies, decision-making support and comprehensive stakeholder engagement.

The twenty-six (26) with their diverse expertise and network, uniquely position SEEDS to make a significant impact on the electrification of thermal demand in buildings. This initiative not only aims at delivering immediate benefits in terms of energy efficiency and carbon reduction but seeks to pave the way for broader adoption and implementation of its solutions across Europe, thereby contributing to the global efforts against climate change.

This deliverable presents the status of the selected sites, the features and the current status of the technologies installed and used on each site. The integrated approach is also presented for each site, along with the circular design and the circular economy principles followed in each case, taking into consideration the unique needs and characteristics of each

building. The goal of this deliverable is to provide an overview of each demo site and the ambition, the activities and the studies implemented in each case as well as the assessment methods followed. The cost assessment for the demos sites was also included as a part of this deliverable.

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ABBREVIATIONS AND ACRONYMS

Abbreviation	Description
BIM	Building Information Model
BMS	Building Management System
CAPEX	Capital expenditures
OPEX	Operational expenditures
CO_2	Carbon dioxide
CEAP	Circular Economy Action Plan
CV	Controlled Ventilation
DBE	Dynamic Building Envelope
DGNB	Deutsche Gesellshaft für Nachhaltiges Bauen
DHW	Domestic Hot Water
DRY	Design Reference Year
DSM	Demand Side Management
DSO	Distribution System Operator

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EPB	Energy Performance Certificate
EPDs	Environmental Product Declarations
ETICS	External Thermal Insulation Composite System
EV	Electric Vehicle
EU	European Union
GHG	Greenhouse gas
GWP	Global Warming Potential
HP	Heat Pump
HVAC	Heating, ventilation, air-conditioning
IoT	Internet of Things
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Analysis
LPG	Liquefied Petroleum Gas
LV	Low Voltage
MPC	Model Predictive Control
MC	Monitor and Control
NPV	Net Present Value
ORC	Organic Rankine Cycle
PLC	Programmable Logic Controller
PV	Photovoltaic
PVT	Photovoltaic Thermal
RES	Renewable Energy Source(s)
SCADA	Supervisory Control and Data Acquisition
SRI	Smart Readiness Indicator
TBS	Technical Building System
TES	Thermal Energy Storage
TSO	Transmission System Operator
VRF	Variable Refrigerant Flow
VRV	Variable Refrigerant Volume
WFD	Waste Framework Directive

Table 1: List of acronyms and abbreviations

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1 INTRODUCTION

1.1 AIMS AND OBJECTIVES OF THE DOCUMENT

This deliverable aims at presenting the current status of the selected pilot and replication sites. The demo sites are divided into two categories: new construction and renovation sites. In each category, a description of the demo site is presented to allow all interested parties to have a clear understanding of the current status, the features and the existing technologies.

For the new construction site, this deliverable presents the design and the ambition for the site when the construction is completed. For the renovation sites, the site assessment is analysed along with the methodology used for the evaluation of the current condition. In addition to this, the technical analysis and the evaluation results are presented for each demo site to provide a clear view on each site's assessment. The integrated approach is also presented for each of the pilot sites, taking into account the circular design and circular economy principles that are expected for each site.

The key objectives of this deliverable are:

- to provide a comprehensive overview of each demo site, its current status and for the construction site the ambition at the end of the construction phase.
- to present the activities that took place during the pilot site surveys conducted in each of the renovation sites, the assessment methods and the studies implemented.
- to present the integrated circular design approach, the cost assessment and the circular economy principles for each demo site.

1.2 RELATION TO OTHER ACTIVITIES IN THE PROJECT

The following table (Table 2) presents the relation to other activities within the SEEDS project.

Activity	**Description**
T2.3	The results of T2.1 will be used as input for T2.3.
T2.4	The results of T2.1 will be used for Task 2.4 to support the development of the

	electrification solutions and optimize the buildings' performance.

Table 2: Relation to other activities

1.3 CONTRIBUTION OF PARTNERS

The following table (Table 3) presents the partners' contribution to Task 2.1 "Pilot Site Surveying and Condition Assessment" and Task 2.2 "Integrated circular design and cost assessment".

Participant Short Name	Contribution
AInergy	Input on the optimisation processes for the Danish demo site.
BWS	Input for the Belgian demo site.
CDK	Danish demo site leader. Input on the current status, the design and the ambition after the demo site construction is completed.
Certh	Input on the Greek demo site and the SRI analysis.
DTU	Input on the energy use estimation, LCA analysis for the Danish demo site.
DUTh	Greek demo site leader, input on the current status of the Greek demo site.
FairC	Input on the Hungarian demo site: energy performance calculations and SRI analysis.
HORBER	Input for the Hungarian demo site: site assessments, BIM model, PV and SRI analysis.
EMI	T2.2 leader, input on the life cycle environmental impact of the Hungarian pilot, input for the LCA
KUL	Input for the Belgian demo site.
PETROL	Slovenian demo site leader, input regarding the site survey and the assessment of the Slovenian demo site.

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RENEL	T2.1 leader, Deliverable leader, collecting and coordinating information provided by the demo site leaders, Greek demo site survey and assessment.
SWECO	Belgian demo site leader, input on the site survey and the current status of the pilots.

Table 3: Partners' contribution to T2.1 and T2.2

1.4 STRUCTURE OF THE DOCUMENT

The deliverable is structured as followed:

Section 1: Includes the introduction of the deliverable, the aims, the objectives, the relation with other activities within the SEEDS project and the partners' contribution.

Section 2: This section is divided based on the status of the demo sites (construction and renovation sites) and includes the description of the demo sites and their current status. Concerning the sites that are under construction, this section includes the design details and the ambition for the site when the construction is completed. For the renovation sites, this section describes the methodology used for their assessment and the evaluation results.

Section 3: Section 3 includes the integrated approach and the circular economy principles for each of the demo sites. The cost assessment is also included in this section.

Section 4: This section summarizes the deliverable and identifies the future work.

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2 PILOT SITE SURVEYING AND CONDITION ASSESSMENT

2.1 CONSTRUCTION SITE

2.1.1 Danish pilot

The Danish pilot site called “Tech House” is an office building scheduled for completion in 2025. With a total floor area of a little more than 5000 square meters, it includes a heated area of 4800 square meters. The “Tech House” represents a typical modern office space designed in alignment with Denmark’s current building regulations (BR18).

Relevant facts on the building.

- Building type: New Office, to be finished in 2025
- Heating type: District heating
- Estimated electricity generation from PV: 54300 kWh/year
- Heated area: 4800 m²

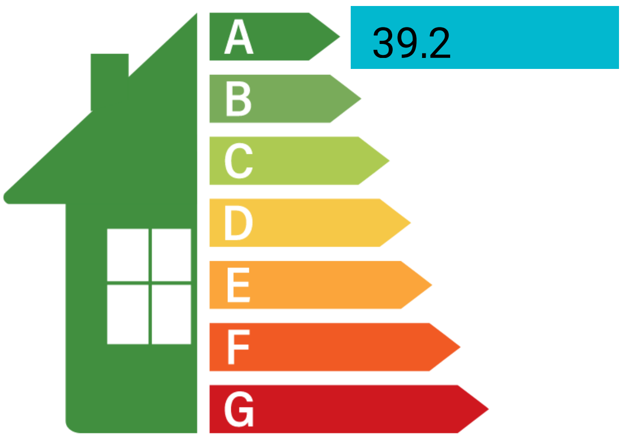

*Figure 1: Energy frame system used in Denmark (*projected energy use includes heating, cooling, ventilation, lighting, and additional electricity for systems)*

The energy assessment is based on quasi-steady-state monthly mean simulations based on DRY (Design Reference Year) data, as mandated by national regulations. The life cycle method uses both electricity and district heat projection data. This approach enables climate-related impact calculations based on location-specific climate data and projections. The building’s mass quantities, derived from detailed quantity take-offs within the developers' Building Information Modelling (BIM) system, form the basis of these calculations, as such the accuracy in the representation of materials and components are based on projected values. For specific materials where the building's products have been finalized, Environmental Product Declarations (EPDs) were used to ensure precise data integration. For instance, the flooring tiles specified for the building feature product-specific EPDs, contributing to more accurate life cycle analysis of their environmental impact. In cases where products have not been specified, the assessment defaults to using generic data, providing a conservative estimate that still aligns with regulatory and industry standards in Denmark.

The predicted energy use (heating, cooling and electricity for building services) is based on current weather data and current standard energy mix. However, future energy-mix is taken into account with projected emission factors as shown in Table 4: *Emission factors, Global Warming Potential used in the assessment (BR18, Table 8)*

below.

Emission factors (GWP)	2025	2030	2035	2040-
Electricity	0,135	0,0470	0,0414	0,0403
District heating	0,0878	0,0713	0,0688	0,0680

Table 4: Emission factors, Global Warming Potential used in the assessment (BR18, Table 8)

2.1.1.1 Current status

The Danish pilot site "Tech House" building is under construction and is scheduled to be completed in June 2025, where it will open for company residents. The building is at this moment closed on the outside and the façade is being established. Hereafter the indoor construction can commence in the winter months.

The story behind Dandy Business Park began with a wish among companies wanting a place that combined high-tech facilities and sustainability strategies. By establishing a community of companies with a focus on research, development and collaboration, Dandy Business Park created a new model for business development in Denmark. The park is designed to attract both established companies and startups and offers flexible office solutions as well as access to innovation labs, common areas and recreational areas.

The Tech House (Pilot building) is a commercial office building, offering approximately 300 desk spaces within a 5,000 square meter facility.

Figure 2: The DK pilot site

2.1.1.2 Design

Being built as part of Dandy Business Parks growth strategy, Tech House is in line with the master plan that has been drawn up for the whole business area. The building was designed by ERIK Arkitekter, based on a desire for a building that, in terms of content and construction, is similar to the existing buildings, but which has a different look on the outside.

The building owner has from the start demanded that the construction will live up to a DGNB Gold certificate. This certificate is a proof of the degree of more sustainability in the construction of the building. By demanding a Gold Certificate, the Dandy Business Park is asking for the construction of Tech House to meet a total performance index of 65% or higher.

The **DGNB certification system** focuses on three essential paradigms, which include:

- Lifecycle assessment
- Holistic approach
- Performance orientation

With the lifecycle assessment, the certification accounts for a project's impact throughout its life, from planning to construction, to use and to deconstruction, taking a holistic approach to buildings, measuring impact on ecology, economy, and socio-culture.

The **quality measure**, which is used for awarding the corresponding award, is divided into five areas:

- Environmental quality (22.5%)

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- Economic quality (22.5%)
- Sociocultural and functional quality (22.5%)
- Technical quality (15%)
- Process quality (12.5%)
- Site quality (5%)

The environmental, economic, and sociocultural/functional qualities are equally weighted and serve as the primary criteria for assessment. For a holistic approach, the technical and process quality is also measured. However, these measures have a smaller contribution to the overall weight of the assessment. Lastly, the certification also considers the location.

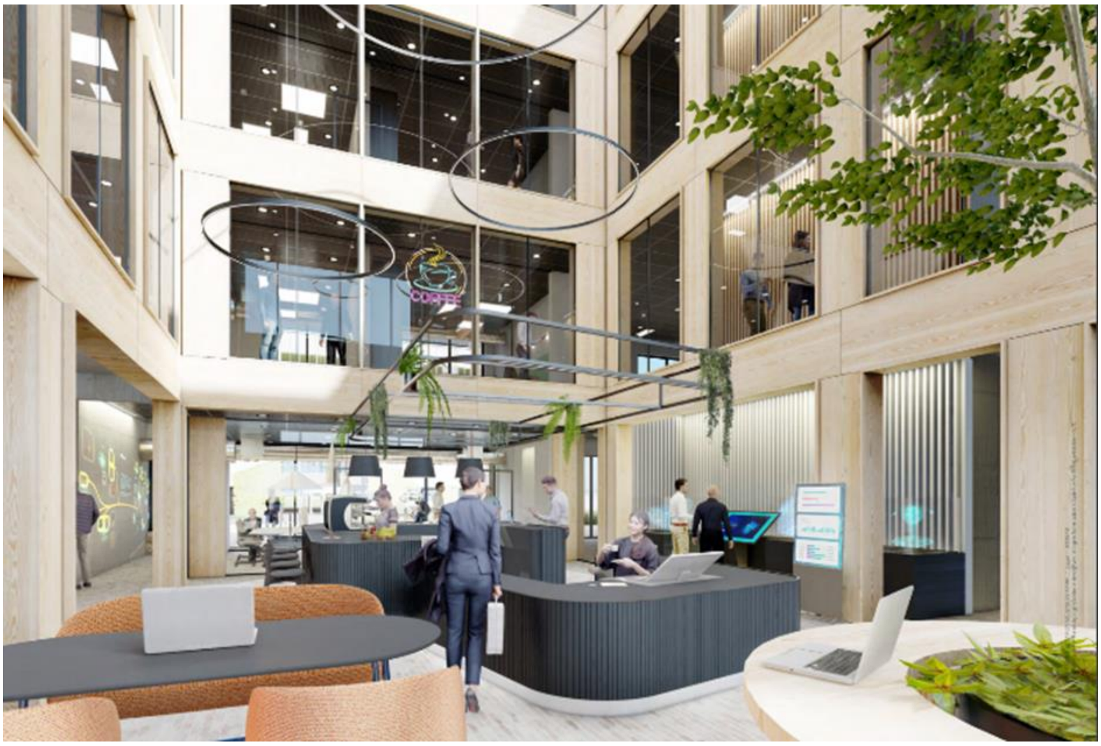

Figure 3: The DK pilot site representation

Figure 4: Top view of the DK pilot site

2.1.1.3 Ambition

Sustainability plays a major role in the park's architecture and operations, which includes energy-efficient buildings, green energy solutions, and initiatives that reduce waste and carbon footprint.

Dandy Business Park, owner of the building is deeply committed to minimizing environmental impact through sustainable practices. The Tech House building has been offered as a testbed for SEEDS free of charge, demonstrating Dandy Business Parks commitment to fostering innovation and sustainable growth. This also aligns with Vejle municipality’s strategic investments in business development.

Building on knowledge from the previous buildings within the same area and using the newest technology in an already known software setup gives Dandy Business Park a head-start to consider new features and technologies that can enhance the sustainability and function of the building.

Circular economy in construction is thought in from the beginning, through reusing and recycling materials from demolition projects, such as iron, metal, asphalt, concrete and wood, in the new construction project. This reduces the amount of waste and reduces the need for newly produced materials, which leads to a significant CO_2 saving. Intelligent energy management systems for storing and intelligently managing energy, which optimizes energy consumption and reduces waste is already being used in existing buildings and will be integrated into Tech House. In this way Dandy Business Park is able to compare the different buildings and make changes that apply for several building, leading to an environmental as well as an economic advantage.

Through the combination of circular design and advanced technology, DANDY Business Park demonstrates their commitment to creating sustainable and innovative workspaces that meet the needs of the future.

2.2 RENOVATION SITES

2.2.1 Belgian Pilot

2.2.1.1 Description of the demo site

The Belgian Pilot site De Schipjes, aims to upgrade the existing energy system of a group of social houses, designed and constructed in the first quarter of the 20th century and located in the centre of Bruges. The houses are two-story brick row houses with a ground floor and a +1 attic, organised around an inner courtyard. The 12 houses add up to a total floor surface of 750m². In 2017 the houses were renovated During this renovation, the windows were replaced by so-called 'monuments glass', which has the exact same look as the original wooden windows but with improved thermal characteristics (U=1.9 W/m²K). To further safeguard the visual identity of the houses, the walls were insulated on the inside. The insulation used, is called 'Aerogel plaster': a thin (2 cm) layer of super-insulating silica-gel (λ=0,028 W/mK) was applied, to limit the spatial implications of adding insulation on the inside of the building, at the same time limiting thermal heat losses to a certain maximum. Each house was equipped with floor heating on the ground floor and radiators in the upstairs bedroom. A local heating district was installed, as well as a small borefield, located at the heart of the inner courtyard that acts as the source of a water-water heat pump that provides the necessary heating for the houses, together with a limited number (due to heritage constraints) of solar thermal collectors. Heritage restrictions are primarily visual in nature: from the public domain, no (components of) technological installations may be visible, such as intake or exhaust grilles for ventilation, PV(T) panels, or solar collectors. Only a limited area of the existing slope roofs could be used to add PV or a solar collector, eventually the solar collector was chosen to pre-heat the thermal network. The existing building outline cannot be changed or enlarged, new constructions need to be executed in similar materials and have to match the feel and look of the existing built environment. The central energy system components are brought together in a wooden energy cabin that was built on the inner courtyard, that blends in the visual ensemble of the garden. Each house is connected to the central energy cabin through the local thermal network, the central BMS (priva) controls the system to provide a comfortable indoor temperature (clock function). A thermostat and temperature sensor, present in each living room, monitor the local temperature and are linked to the BMS. Domestic hot water is locally produced per house, on demand, using a small booster heat pump, using preheated water from the district heating system as heat source.

To make the system more robust with respect to uncertainties (weather, user behaviour), thereby avoiding thermal depletion of the borefield, and to increase seasonal global system

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performance, two air-water heat pumps are added in 2024, as well as two extra boreholes. To safeguard the longevity of the existing borefield installed in 2017 and to explore (or optimise) the seasonal efficiency even further, Sweco and KUL designed and assessed through simulation several hydronic switch schemes, using Builtwins' optimization framework, to enable the system to choose the best possible combination of techniques and flows to guarantee the most efficient outcome. A simulated optimum (allowing switching between multiple modes to increase system performance) was chosen and developed, the tender of this scheme is ready for publication, execution is foreseen from September to December 2024.

Figure 5: View of (top) two heritage houses and the local booster heat pump with small domestic hot water tank, (bottom) the energy cabin and the thermal network at 'De Schipjes'

A digital twin of the houses is designed by Builtwins and used to monitor and control the indoor conditions of each house. To assess the available room for energy system extension in the central energy cabin, a Building Information Model (BIM) of the extended cabin was created by Sweco (scan to BIM based on cloud point of existing situation). This model was updated with the new components and visualises now all technical components. This BIM model will serve as as-built document.

Temperature sensors are added in the houses and an optical glass fibre will be added to the two new boreholes in the borefield, to monitor the temperature in real life. The extra heat pumps and the solar thermal collectors can also be used to regenerate the borefield.

The techniques implemented in the design of 'De Schipjes', are replicated in a second project 'Stijn Streuvels' involving the renovation of a similar housing group around 3 inner courtyards, that are also constructed in the beginning of the 20th century, also in Bruges.

Again, a central energy system will process the energy flows through a small thermal network for this district, fed by a geothermal heat pump, solar thermal collectors and air-water heat pumps, to provide heating/cooling and domestic hot water to 15 small households. MPC will control this clean hybrid collective energy system and based on the living lab experiments with the hydronic switch in 'De Schipjes' pilot, a well-performing hydraulic scheme will be chosen for the 'Stijn Streuvel' pilot.

Figure 6: View of the housing and the central inner courtyard at 'Stijn Streuvels'

2.2.1.2 Methodology considered for the assessment of the demo site condition

For 'De Schipjes', the operation and energy use of the different physical components were evaluated on site by the project team, together with the building owner Mintus and their maintenance company.

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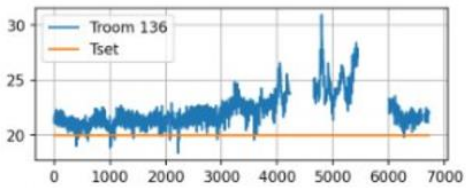
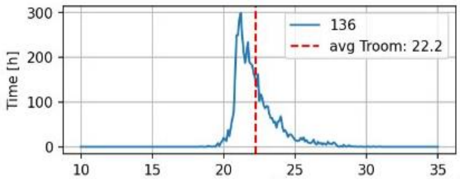
We looked at the one hand to the room temperatures of all the houses and noticed that the setpoint temperatures were almost always reached and that in summer not really high peaks were reached so it could be concluded that cooling wasn't necessary.





Additionally, we also looked at the energy use for heating and DHW and concluded that the DHW demand was rather low for these types of buildings.
Due to this data analysis, we could see that some components (eg. Pumps, solar collector) were not performing as they should and we determined measures to let them work more optimally.

MPC is installed together with extra temperature sensors to monitor and log real time data and link the energy system to the digital twin that was custom made for 'de Schipjes'.

Possible areas of future improvement are defined (solar field, heat pumps, BMS, DHW) and where possible, implemented in the tender documents of the system upgrade with hydronic switch. Additional energy measurements will enable a detailed assessment of the energetic changes made to the system and to further calibrate the MPC. Refining the data and understanding of the current system operation through the installation of complementary measuring devices such as calorimeters and temperature probes in the borefield, will enhance a better sizing of all components and a verification of the physics-based models used.

For 'Stijn Streuvels', the houses and inner courtyards are measured and mapped. Sweco is presizing the components in the energy system, based on the programme and the desired outcome of the building envelope, referring to and learning from the results of 'de Schipjes'. Together with the architect and taking into account the same restrictions as mentioned for 'De Schipjes' that were imposed by Heritage and Urban regulations, the heat loss surfaces and possible insulation systems were discussed and a few insulation types were selected. A heat loss calculation is made by Sweco to determine the necessary power needed.

For Stijn Streuvels, during a preliminary meeting with the Energy label certifier (EPB in Belgium) all minimal U-values are defined for every building envelope component of the Replica site. Subsequently, Sweco provided an estimation of the delta that can be applied to these U-values for accounting thermal bridges with the existing internal insulation in order to refine the heat loss calculations. For the calculated deltas, two values are provided as a range within which the delta will fall. Below are the calculated deltas for the various U-values:

- Exterior wall with 14 cm Multipor Tip Wall** → U = 0.28 W/m^{2}K

=> Delta: 0.07 – 0.14 W/m^{2}K

- Party wall with 5 MW (0.035)** → Ueq = 0.55 W/m²K

=> Delta: 0.10 – 0.21 W/m²K

- Party wall with 5 cm Multipor Tip Wall on both sides** → Ueq = 0.35 W/m²K

=> Delta: 0.06 – 0.13 W/m²K

- Floor on full ground with 16 cm Starbeads Low lambda** → Ueq = 0.19 W/m²K

=> Delta: 0.07 – 0.13 W/m²K

- Ceiling to AOR with 22 cm MW (0.035)** → Ueq = 0.21 W/m²K

=> Delta: 0.02 – 0.05 W/m²K

- Exterior joinery** → Uw = 1.50 W/m²K, g = 0.50, Ug = 1.0 W/m²K

=> Delta: 0.10 – 0.20 W/m²K

Sanitation of the sloped roofs is needed: roof tiles will be recovered and replaced.

2.2.1.3 Detailed technical analysis based on the implementation tool

The BIM model of the energy cabin at 'De Schipjes' is prepared and will be used to aid the execution of the upgrade and adjustments of the existing techniques.

A first SRI assessment was being carried out for 'De Schipjes'. Version 4.5 issued by the SRI support team (support@smartreadinessindicator.eu) was used to conduct the assessment. It follows the methodology outlined in the report on technical support to the development of an SRI for buildings[1].

The assessment was completed for the current state of the houses, before the addition of air-sourced heat pumps and other components, described in the previous subsections. The domains cooling, dynamic building envelope and electrical vehicle charging are absent in this use case. The weighting factors for the domains are the default values for a residential building in the West Europe region.

The results are presented in the figures on the following page. Aggregated, the **total SRI score attains 18.4%** and thereby falls in the lowest category, "Lower than 20%". However, there are large underlying differences between the different domains. For heating and domestic hot water, the scores are 42.8% and 50.0% respectively. Heating is already controlled by an MPC that was installed during the 2017 renovation [1]. All consumption data for heating and DHW is monitored. Electricity (score of 25.0%) is tracked on building level, but not in real-time or with forecasting. Electricity production and storage are not applicable.

[1] European Commission: Directorate-General for Energy, Verbeke, S., Aerts, D., Reynders, G., Ma, Y. et al., Final report on the technical support to the development of a smart readiness indicator for buildings – Final report, Publications Office, 2020, https://data.europa.eu/doi/10.2833/41100

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The overall SRI score is however impacted heavily by domains that reach a blank score (0.0 %): ventilation and lighting. The air flow cannot be controlled and is not reported. Likewise, lighting is controlled by manual on/off switches, without detection or dimming options. Finally, monitoring and control reaches a low score of 9.4%. The absence of HVAC/TBS/DSM interaction control, smart grid integration, and reporting lead to this low score.

To conclude, the low aggregated SRI score is a combination of mediocre scores on the domains heating, domestic hot water and electricity, which are the most relevant domains for the SEEDS project, and very low scores for the domains of ventilation, lighting and monitoring and control.

Smart Readiness Indicator for Buildings

The SRI calculations have been performed with an experimental tool. Please note that the scores and the visual presentation of results are solely provided for testing purposes. Using this experimental tool can by no means lead to any claims on an actual score or certificate for a building.

SRI spreadsheet tool Version 4.5

TOTAL SRI SCORE	**18,4%**	**SRI CLAS!**	**Lower than 20%**

IMPACT SCORES

Energy efficiency	26,0%
Energy flexibility and storage	14,3%
Comfort	22,7%
Convenience	15,6%
Health, well-being and accessibility	0,0%
Maintenance and fault prediction	20,8%
Information to occupants	32,0%

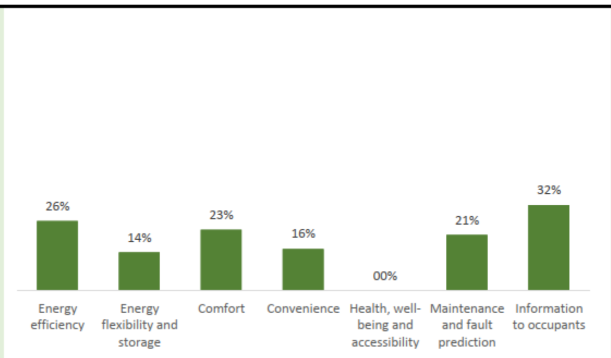
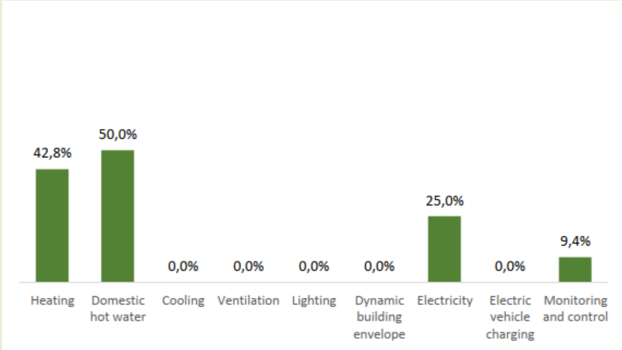


Figure 7: Smart Readiness Indicator of the current state of "De Schipjes" – Total SRI Score and Impact Scores

DOMAIN SCORES

Heating	42,8%
Domestic hot water	50,0%
Cooling	0,0%
Ventilation	0,0%
Lighting	0,0%
Dynamic building envelope	0,0%
Electricity	25,0%
Electric vehicle charging	0,0%
Monitoring and control	9,4%



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	55,6%	22,2%	55,6%	36,4%	60,0%	20,0%	50,0%
Domestic hot water	66,7%	33,3%	0,0%	33,3%	0,0%	50,0%	66,7%
Cooling	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Ventilation	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Lighting	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Dynamic building envelope	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electricity	25,0%	0,0%	0,0%	0,0%	0,0%	25,0%	50,0%
Electric vehicle charging	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Monitoring and control	0,0%	0,0%	0,0%	11,8%	25,0%	18,2%	11,1%

AGGREGATED SCORES

Key functionality 1 - building	23,4%
Key functionality 2 - user	17,6%
Key functionality 3 - grid	14,3%

Figure 8: Smart Readiness Indicator of the current state of "De Schipjes" – Domain Scores, Detailed Scores and Aggregated Scores

2.2.1.4 Evaluation results and identification of areas for improvement

Following areas for improvement were identified:

- Production of **Domestic Hot Water for "De Schipjes": demand is low** and the installed booster pumps seem like an overkill, when taking into consideration the actual demand and the maintenance cost per pump. An **electrical boiler** seems much more suitable for these small, social dwellings for 1 to 2 persons: for Stijn Streuvels individual electrical boilers will be installed per house.
- Again: as the demand for DHW in these types of dwellings is very low, the **effectiveness of the solar boiler** that was installed in "De Schipjes", does not match the actual behaviour of the social housing inhabitants. To exploit solar energy in this particular heritage context of these dwellings typical for the city of Bruges, PV or PVT panels seem like a better option: they can assist in regenerating the borefield and/ or produce electricity that can be used for the centralized systems.

- In general, the installation of **solar panels** (PV or PVT) has a positive effect on the energy label scoring in Belgium (EPB certification).
- The **airtightness** of these types of dwellings plays an important factor in the design assumptions and sizing of the systems: For the “Stijn Streuvels” renovation, which includes an upgrade of the external building envelop, all uncertainties concerning the building envelop, renovated in 2017, that impact the actual heat demand in “De Schipjes” case, have been listed and special attention will be paid during execution of the planned “Stijn Streuvels” renovation, to secure the airtightness of the building envelope as much as possible.
- To **avoid depletion of the borefield, passive cooling** could be applied through the floor heating system and used to regenerate the borefield. This is only true if there is an actual need to cool the dwellings, at this moment in time there is no request of the inhabitants to do so (at “De Schipjes”), while the building owner considers this as a nice-to-have as long as it is passive cooling (for “Stijn Streuvels”). Moreover, PVT panels generate low-temperature heat that is suited for borefield regeneration.
- The **aerogel** that was applied in “De Schipjes” as an internal wall insulation, is not as performant as initially estimated. Other, more robust and better performing materials are preferred in this context (flexible quality of the gel makes it a less suited solution for these dwellings).
- Instead of adding an extra building as was done for “De Schipjes”, a centrally located, already existing building, currently used as a storage space, will be used in Stijn Streuvels to accommodate the **common technical room;**
- For Stijn Streuvels: as the **attic height is not suitable** for human occupation (urban legislation), the available, often adjacent attics are used for heat distribution (as opposed to the underground heat network in De Schipjes) and for the installation of ventilation equipment for the different dwellings (accessible for maintenance or future improvements);
- At the Stijn Streuvel site, s**ufficient space is available for geothermal drilling**, but quite a few conditions have to be taken into account (existing trees, future rainwater tanks, and swales). Also: the difficulty in bringing the drilling machine onto the site, might increase basic investment costs. Alternatives are being explored.

2.2.2 Hungarian Pilot

2.2.2.1 Description of the demo site

The demo building of the Hungarian pilot is located at the XVI. district of Budapest, called “Mátyásföld” at the corner of Újszász street and Prodám street.

The flats owned by the Municipality of the XVI. district of Budapest, which can be rented by tender by residents of the district or by employees for at least 6 months of any institution run by the municipality such as public service, public servants, health service, or public education. The size of each apartment is 22 m^2.

Figure 9: Hungarian demo building, view from Újszász street

The building was built in the early 1960s as an unmarried officers' hostel, composed of ground floor + 2 storeys with a flat roof. In the 1990s, the building was converted into a 48-apartment building, a pitched roof was added and the staircase was extended. The newly created attic space was used for storage, 1 per each apartment. The roof pitch is 30° and is of two-post pitched timber construction.

The building has a mid-rise, long-wall construction system with 38 cm brick walls with 4.2 - 2.0 - 4.2 m span distance. The slabs are typically prefabricated: in the wide tracts, most likely hollow-core slabs, while above the corridor, monolithic reinforced concrete slabs. The windows were originally of timber construction traditional double sash windows, but these are now only found in a few rooms (e.g. upstairs common rooms) and have been replaced by timber construction with insulating glazing and later by plastic construction. The corridor and the staircase also have plastic windows.

At present, the apartments are heated individually by one gas-fired convector in each room, there is no permanent heating in the utility rooms, and occasional electric radiators are used in the bathrooms. Domestic hot water (DHW) is provided by electric boilers of approximately 30-40 litres. There is no cooling or mechanical ventilation in the building, and there is no any Renewable Energy System installed either.

Figure 10: The building service equipment: the individual gas heater in the room / the electric heater in the bathroom / electric boiler for DHW / kitchen

2.2.2.2 Methodology considered for the assessment of the demo site condition

Both **quantitative and qualitative methods** were used to assess the demo site condition:

- site visits.
- literature review.
- research of the existing documentation about the building.
- laser scanning and measurement of the building.
- non-destructive testing.
- BIM model.
- energy performance calculations.
- energy data from the Municipality.
- Smart Readiness Indicator calculations.

Since the building is in operation and habited there were not any possibility to do **some destructive testing** about the existing structures. Therefore, some structures (eg. slab constructions) will be determined later, during the renovation process.

Site visits: several site visits were carried out by the SEEDS partners.

Literature review: research in the Hungarian Archives about the original building.

Research of the existing documentation about the building: the Municipality provided the architectural floorplans of the refurbishment in 1993.

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Laser scanning and measurement of the building; during the site visits laser measurement were taken.

BIM model: After finalizing the detailed measurements, literature review and research. All data were available to develop the BIM model. The BIM model of the building was prepared and will be used to aid the execution of the refurbishment and adjustments of the existing techniques.

Energy performance calculations: The theoretical peak capacity of the whole building for heating is 111 kW, the estimated heat demand is 189 MWh/a. Therefore, the specific heat demand (for heating) is 134 kWh/m^2/a. The total specific primary energy consumption including heating and DHW is 198 kWh/m2/a, which far exceeds (260%) the current required value for residential buildings of near zero energy demand" (76 kWh/m^2/a). The current **building is classified F** in this way.

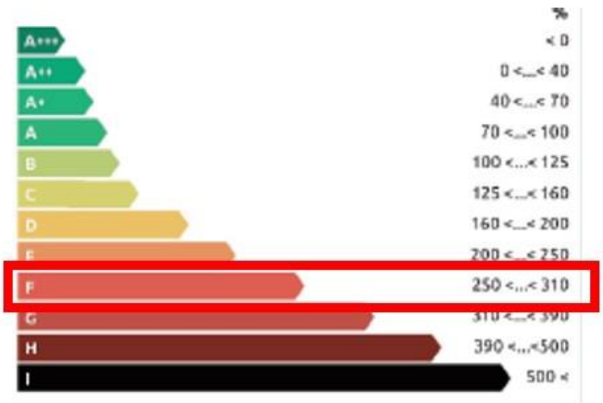

Figure 11: Energy performance of the current building

Energy use data from the Municipality: The natural gas consumption of whole building average of the last three years is 15,000 m^3/a, 161 MWh/a. The heat demand for heating calculated from the fact gas consumption is 116 MWh/a, which is much less than the theoretical heat demand. This may be due to low utilization of the building.

Smart Readiness Indicator calculations: The detailed methodology for calculating the Smart Readiness Indicators (SRI) was provided the SRI Support Team (ec.europa.eu). In this case the simplified method (method A) which is mainly suitable for residential buildings) was used.

2.2.2.3 Detailed technical analysis based on the implementation tool

Based on the detailed technical measurements the BIM model of the demo building was developed.

Figure 12: Demo building in the current state, the BIM model (view from Újszász street)

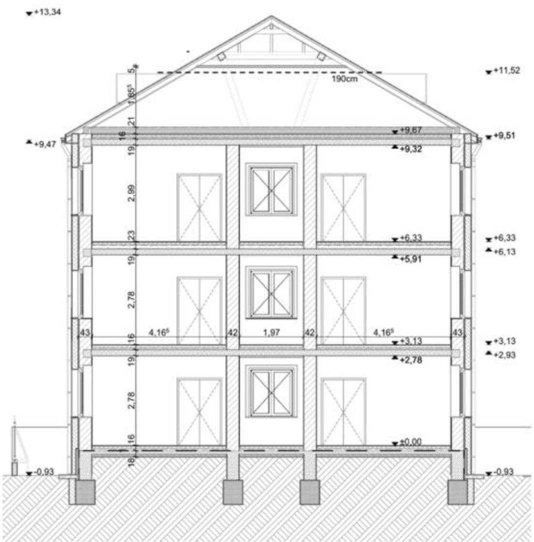

Figure 13: The cross section of the demo building

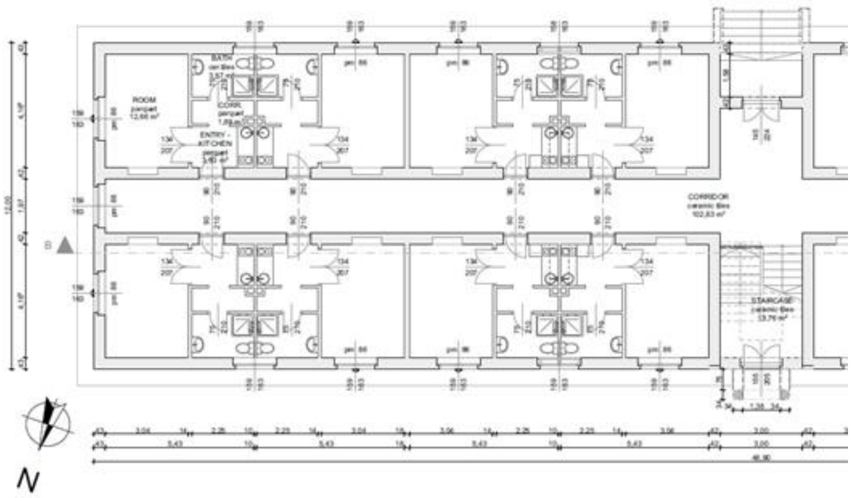

Figure 14: The floorplan of the building part that is planned to be upgraded by SEEDS (ground floor)

The operation of the existing gas and electrical systems was evaluated on site. Gas burners are operating per apartment without any sensors, only manual setting is possible. The electricity is measured per apartment with an energy meter.

The apartment and its outdoor environment are not equipped with any sensors, only gas (central) and electricity (per apartment) are measured by DSOs.

The **results of the energy calculations** are shown in chapter 2.3.2 Methodology considered for the assessment of the demo site condition.

The **SRI assessment result**s of the current building are shown in the following figure (

Smart Readiness Indicator for Buildings

The SRI calculations have been performed with an experimental tool. Please note that the scores and the visual presentation of results are solely provided for testing purposes. Using this experimental tool can by no means lead to any claims on an actual score or certificate for a building.

SRI spreadsheet tool Version 4.5

TOTAL SRI SCORE	15,2%	SRI CLASS	Lower than 20%

IMPACT SCORES

Energy efficiency	2,8%
Energy flexibility and storage	40,0%
Comfort	0,0%
Convenience	16,7%
Health, well-being and accessibility	0,0%
Maintenance and fault prediction	0,0%
Information to occupants	0,0%

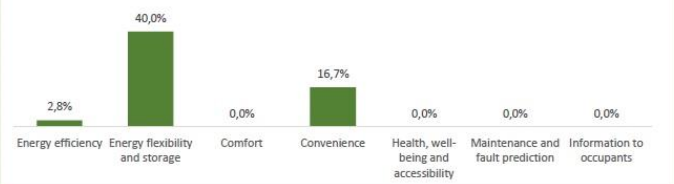

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Figure 15). The weighting factors for the domains are the default values for a residential building in the South-East Europe region.

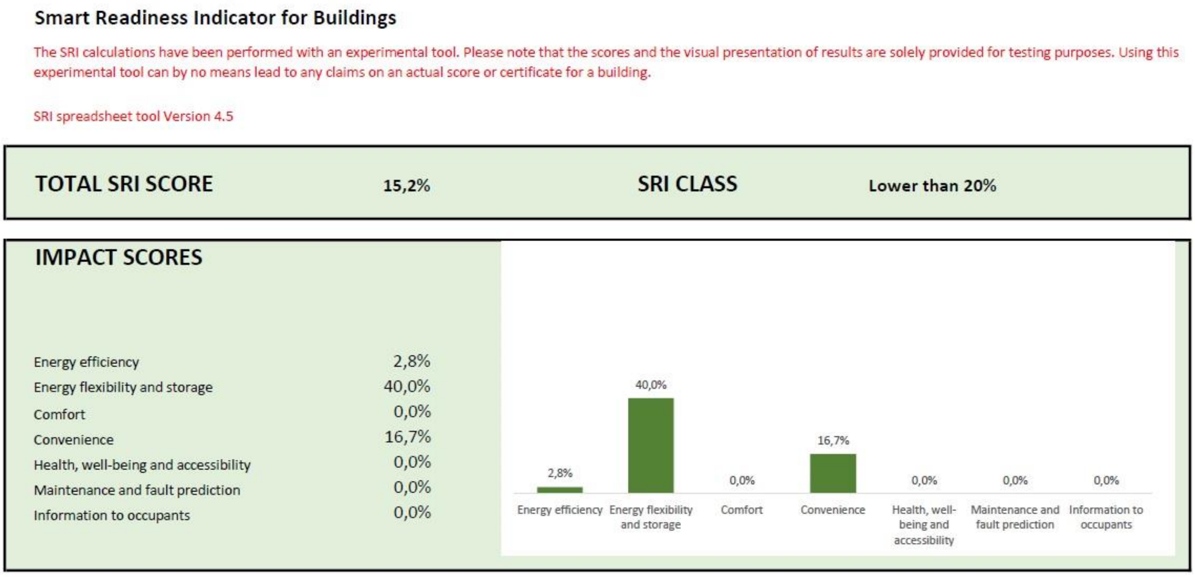

Figure 15: Smart Readiness Indicator (SRI) of the current state, before applying any improvements (Total SRI Score and Impact Scores)

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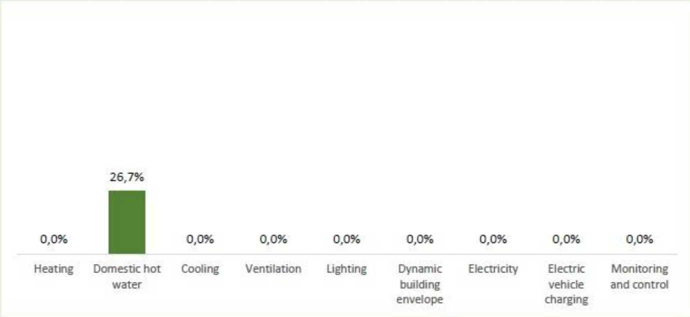
DOMAIN SCORES

Heating	0,0%
Domestic hot water	26,7%
Cooling	0,0%
Ventilation	0,0%
Lighting	0,0%
Dynamic building envelope	0,0%
Electricity	0,0%
Electric vehicle charging	0,0%
Monitoring and control	0,0%



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Domestic hot water	33,3%	40,0%	0,0%	40,0%	0,0%	0,0%	0,0%
Cooling	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Ventilation	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Lighting	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Dynamic building envelope	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electricity	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electric vehicle charging	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Monitoring and control	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

AGGREGATED SCORES

Key functionality 1 - building	1,4%
Key functionality 2 - user	4,2%
Key functionality 3 - grid	40,0%

Figure 16: Smart Readiness Indicator (SRI) of the current state, before applying any improvements (Domain Scores, Detailed Scores and Aggregated Scores)

The figure above provides an overview of the building's SRI score, revealing several important aspects related to energy performance, needs of the occupant and energy flexibility. With a total **SRI score of 15.2%,** the building falls into a category below 20%, indicating that **its smart readiness is low**. The impact scores highlight that the building performs reasonably high score in the field of Energy flexibility and storage (400%) due to the domestic hot water storage tanks in the apartments. These storage tanks are automatically controlled, and charging is scheduled. The convenience is 16.7% and the energy efficiency score is 2.8% influenced also by the DHW storage tanks and the other components are 0%.

2.2.2.4 Evaluation results and identification of areas for improvement

Based on the technical analysis of the demonstration building the following suggestions for improving energy efficiency and smart readiness were determined:

More stages for refurbishment were defined to increase the property's value:

1) **<u>Step A</u>**

This step refers to the SEEDS project. The designed state includes:

- External Thermal Insulation Composite System (ETICS) on the facade via innovative recyclable/demountable material
- electrification via VRV heating & DHW system in 12 apartments (500 m^2)
- smart solutions, integrated microgid system
- 5 kW solar panel, storage and EV charger
- BIM & digital twin
- replacing windows
- thermal insulation of attic slab

The complete thermal insulation of the building envelope is planned (thermal insulation on the facades and the slab of the attic together with the replacement of the existing windows). The planned PV system will be integrated in the facade.

The heating and DHW system will be replaced by VRV (heat pump) system in the selected 12 apartments. It is combined with hydrobox which heats central DHW storage. DHW storage would be extended to a buffer thermal storage in order to fit for participation in balancing of LV electricity grid. The relevant part of the heating system will be equipped with a sensor to measure efficiency. The electrical network of the building will integrate the newly installed PV, storage, and EV-charger equipment. Additional energy measurements will be placed at the DSO connection together with mandatory reverse-feed protection. The communication between system components (measured values and setpoints) will be established via local ethernet network.

The planned controllable microgrid control system will coordinate the operation of electricity generators, storage and consumers. The physical electricity management solution is a wall-mounted control cabinet, which has a communication connection with the building's heat pump, electric car charging and solar system, through which it keeps their operation at the current economic and technical optimum. The regulation also requires sensor measurement of the building's total consumption and is also in communication with the control cabinet.

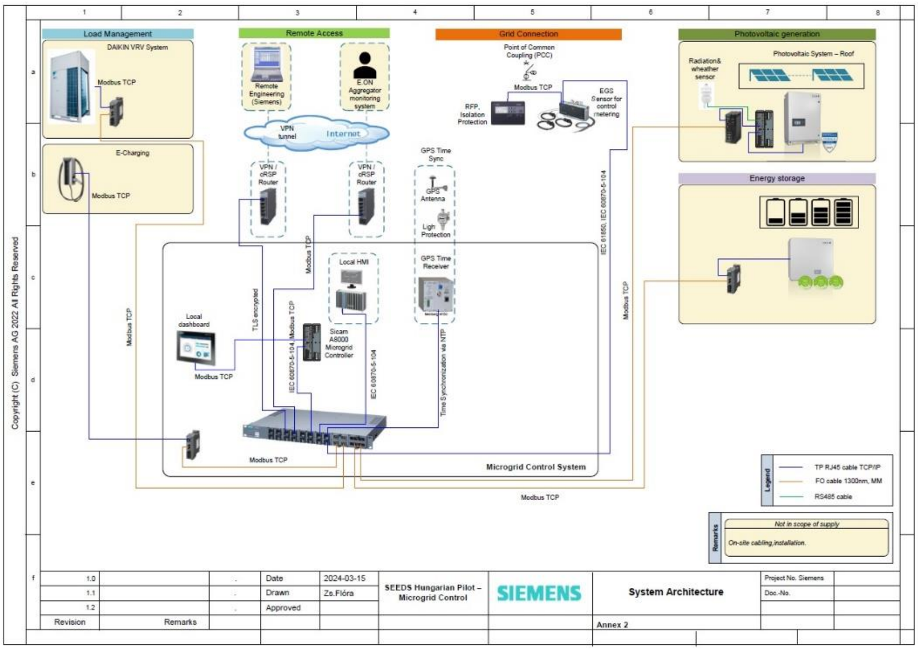


Figure 17: System architecture of the microgrid control

2) Step B

An alternative to Step A includes the following:

- merging housing units to create larger apartments (2*22m^2 = 44m^2)
- extension of the heating system: central gas boiler in the remaining residential units
- heat recovery ventilation (in 12 apartments)

3) Step C

This step will supplement Step A by:

- merging housing units to create larger apartments (2*22m^2 = 44m^2)
- new balconies on the façade to improve comfort (with vegetation and PV as a shading device)
- heat recovery ventilation
- extension of the VRV heating and DHW system for the remaining apartments (building)
- extension of the integrated microgrid system (including the heat recovery ventilation)
- larger solar power plant (facades, balconies, roof)
- shading of windows.

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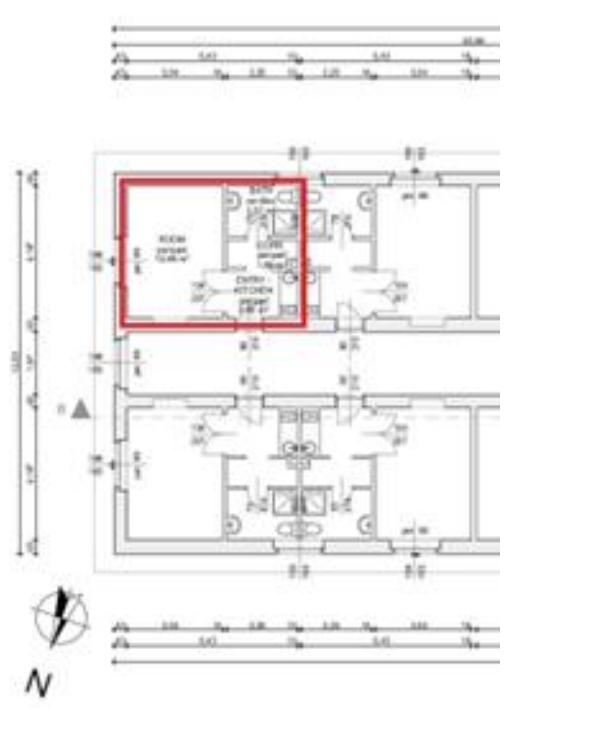

Figure 18: Original state

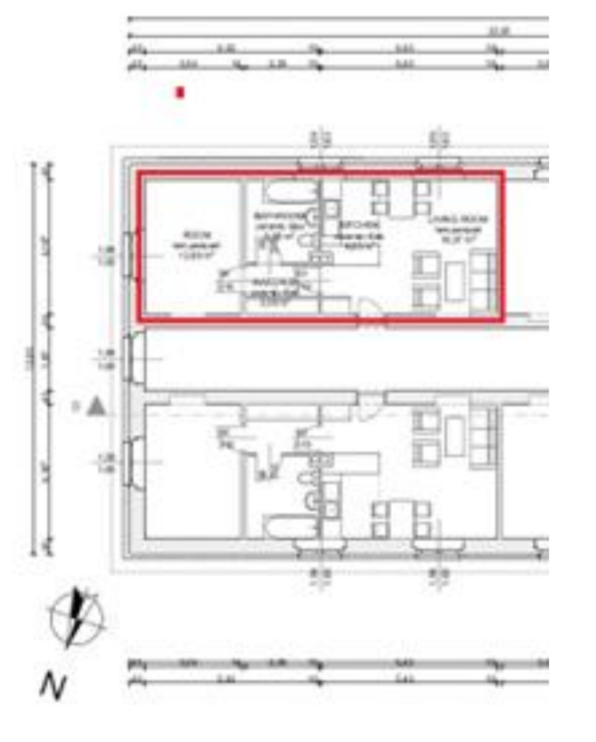

Figure 19: Step C, merged housing units

4) **Step D:**

This step will supplement the previous step (Step C) by:

- new roof structure and built-in attic to create new apartments
- extension of the VRV heating, DHW system and heat recovery ventilation for the new apartments (built-in attic)
- new elevator

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The SRI results of the upgraded building part (app. 500m²), after the refurbishment (Step A) are presented in the following figure (

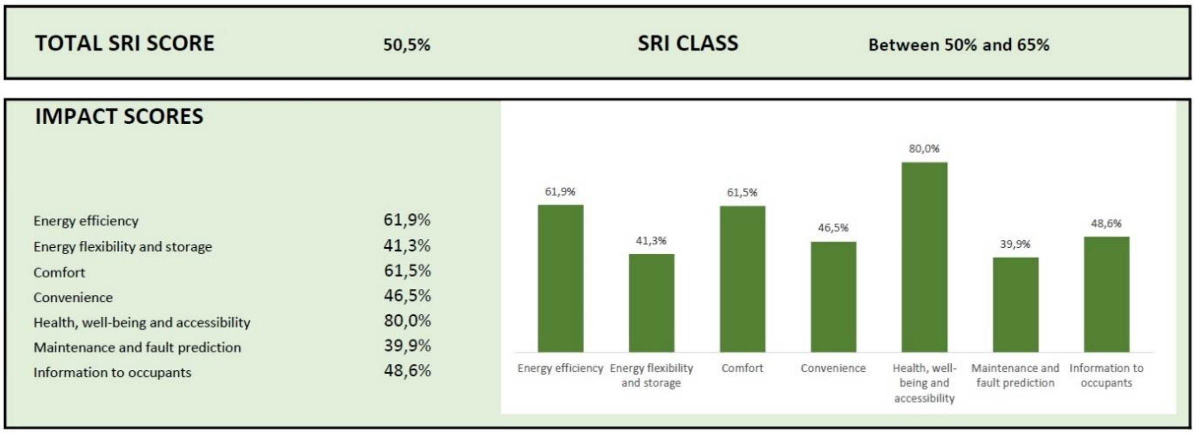


Figure 20).

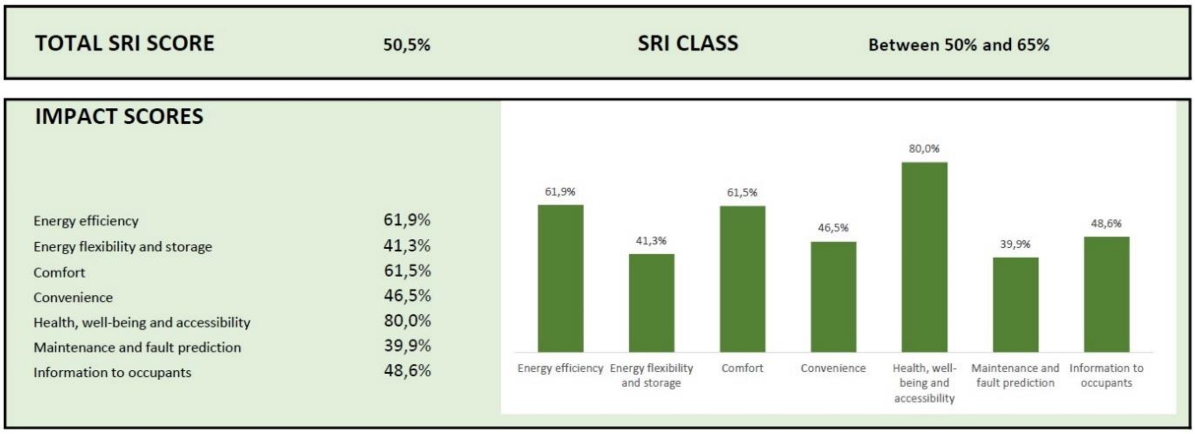
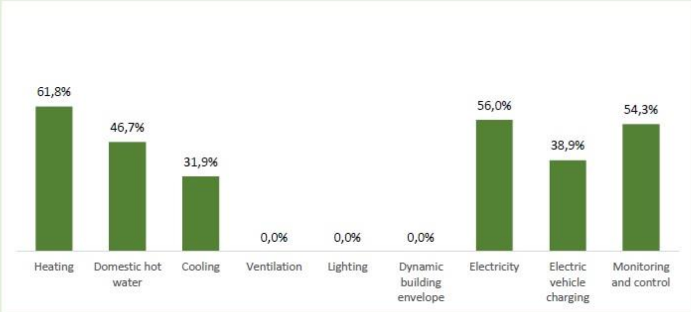


Figure 20: Smart Readiness Indicator, Step A (Total SRI Score and Impact Scores)

DOMAIN SCORES

Heating	61,8%
Domestic hot water	46,7%
Cooling	31,9%
Ventilation	0,0%
Lighting	0,0%
Dynamic building envelope	0,0%
Electricity	56,0%
Electric vehicle charging	38,9%
Monitoring and control	54,3%



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	83,3%	33,3%	100,0%	75,0%	100,0%	50,0%	66,7%
Domestic hot water	66,7%	40,0%	0,0%	40,0%	0,0%	50,0%	33,3%
Cooling	50,0%	16,7%	57,1%	42,9%	66,7%	25,0%	0,0%
Ventilation	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Lighting	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Dynamic building envelope	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electricity	60,0%	66,7%	0,0%	40,0%	0,0%	33,3%	66,7%
Electric vehicle charging	0,0%	25,0%	0,0%	66,7%	0,0%	0,0%	66,7%
Monitoring and control	50,0%	66,7%	0,0%	42,9%	0,0%	50,0%	33,3%

AGGREGATED SCORES

Key functionality 1 - building	50,9%
Key functionality 2 - user	59,2%
Key functionality 3 - grid	41,3%

Figure 21: Smart Readiness Indicator, Step A (Domain Scores, Detailed scores and Aggregated scores)

The SRI of the current state of the demo building was quite low (15.2%), but after upgrading (step A) the SRI score was significantly increased (50.5%), indicating significant advancements in key areas.

Impact Scores:

- **Energy Efficiency**: Improved from 2.8% to 61.9% indicating that significant energy efficiency measures were introduced by the result of better control of the room temperature.
- **Energy Flexibility and Storage**: Increased from 40.0% to 41.3% mainly because of the smart grid integration and on site storge of energy.
- **Comfort**: in the current state it is 0% but increased to 61.5% due to steps to increase the thermal comfort of the occupants by variable control of cooling and heat generator production capacity (depending on the load or demand) and the individual room controls are in communication between controllers and to BACS.
- **Convenience**: Improved from 16.7% to 46.5%, due to mainly the installation of EV changer and the individual room controls.

- **Health, Well-being, and Accessibility**: Increased from 0% to 80.0%. This high increase in impact score illustrates that the building was upgraded with a smarter control system that improves indoor air quality compared to original control, thereby improving the well-being of building occupants and having a positive impact on their health.
- **Maintenance and Fault Prediction**: in the current state it is 0% but improved to 39.9%. Indicating that the information to occupants and facility managers regarding the heating system performance and local electricity generation become available after the refurbishment.
- **Information to Occupants**: Improved from 0% to 48.6%, because of the installed systems reports real time energy use and electricity charging and consumption status to occupants.

The SRI assessment shows that the upgraded building (step A) needs further intervention, particularly in areas of lightning, ventilation and dynamic building envelope. The SRI results of the upgraded building, after the refurbishment (Step C and D) are presented in the following figure (

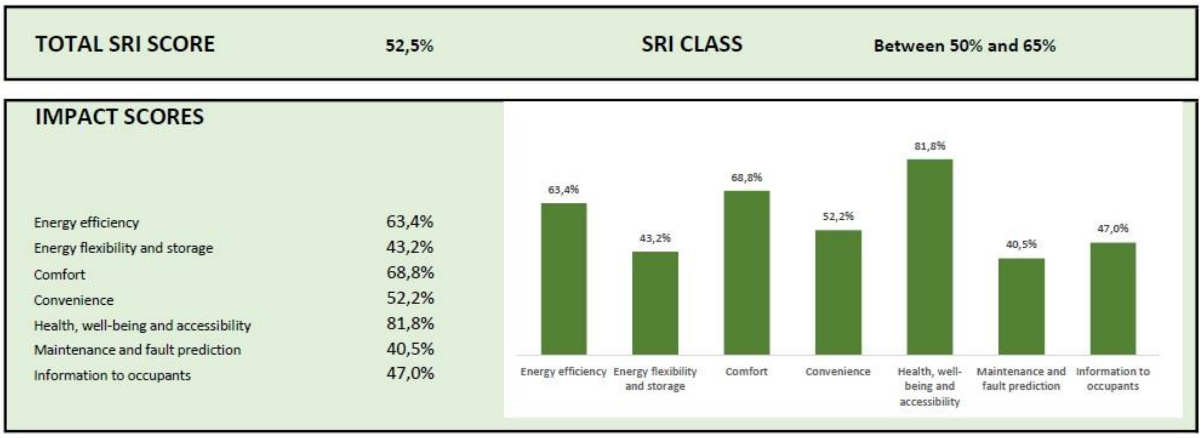


Figure 22).

Compared to Step A it is shown that the impact scores included in the group of “The Energy flexibility and storage” are the same. All the other impact scores (both the “Energy performance and operation” and the “Response to the needs of the occupants”) are slightly increased. Due to the installation of heat recovery ventilation the domain score of ventilation was increased from 0% to 68.8%.

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TOTAL SRI SCORE	52,5%	SRI CLASS	Between 50% and 65%

IMPACT SCORES

Energy efficiency	63,4%
Energy flexibility and storage	43,2%
Comfort	68,8%
Convenience	52,2%
Health, well-being and accessibility	81,8%
Maintenance and fault prediction	40,5%
Information to occupants	47,0%

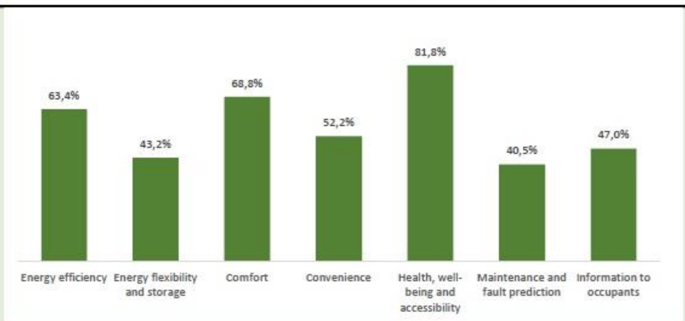
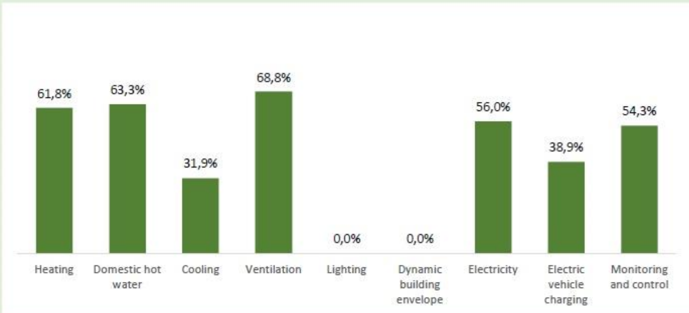


Figure 22: Smart Readiness Indicator, Step C and D (Total SRI Score, Impact Scores)

DOMAIN SCORES

Heating	61,8%
Domestic hot water	63,3%
Cooling	31,9%
Ventilation	68,8%
Lighting	0,0%
Dynamic building envelope	0,0%
Electricity	56,0%
Electric vehicle charging	38,9%
Monitoring and control	54,3%



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	83,3%	33,3%	100,0%	75,0%	100,0%	50,0%	66,7%
Domestic hot water	100,0%	60,0%	0,0%	60,0%	0,0%	50,0%	33,3%
Cooling	50,0%	16,7%	57,1%	42,9%	66,7%	25,0%	0,0%
Ventilation	66,7%	0,0%	100,0%	100,0%	83,3%	50,0%	33,3%
Lighting	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Dynamic building envelope	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electricity	60,0%	66,7%	0,0%	40,0%	0,0%	33,3%	66,7%
Electric vehicle charging	0,0%	25,0%	0,0%	66,7%	0,0%	0,0%	66,7%
Monitoring and control	50,0%	66,7%	0,0%	42,9%	0,0%	50,0%	33,3%

AGGREGATED SCORES

Key functionality 1 - building	52,0%
Key functionality 2 - user	62,4%
Key functionality 3 - grid	43,2%

Figure 23: Smart Readiness Indicator, Step C and D (Domain Scores, Detailed Scores and Aggregated scores)

2.2.3 Greek Pilot

2.2.3.1 Description of the demo site

The Greek demo site refers to a student dormitory building inside the Democritus University of Thrace (DUTH) Campus, built in 1997. The demo site is located in Kimmeria municipality, close to the city of Xanthi in the Thrace region. The building's specific location coordinates are 41.1468407° latitude and 24.9140676° longitude. In this demo site, the renovation is focused on the dormitory block 'Building C1', which is part of the total campus area (Figure 24).

Figure 24: Greek Pilot - C1 building

The C1 building is a student dormitory with 68 rooms. During the implementation of the SEEDs project, 20 of them will have relevant interventions. The 20 dwellings account for a 300 m^2 floor area and will be the Greek pilot case for the SEEDs project. They are heated by a central oil boiler supported by a solar-biomass system through the piping network, with no cooling system. There are radiators for space heating and a central storage tank for DHW in individual rooms needs for the C1 building. A solar thermal field and a geothermal field are nearby, and SEEDS will optimally use these fields for C1 building. There is a central storage tank for DHW located at the basement of the building. No individual storage tanks in each student room.

Regarding the key innovations which will be carried out during the implementation of the SEEDS project, there is:

1. An innovative PV and Reflection System for Renewable Energy Generation,
2. An innovative multi-source (air, geothermal, solar thermal) HP with natural refrigerant, for heating and cooling, optimized electrification systems dimensioning at design phase.
3. Job scheduling optimizer at planning phase.
4. Data driven AI solutions for
    a. Smart Modulation control for multi-source HPs,
    b. Smart Tracking for Reflector systems,

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c. Smart Predictive Maintenance for Electrification Systems (PVs and HPs), and
d. Smart Thermal Comfort and Energy Consumption Management.
5. Data-driven AI solutions for microgrid power flow analysis, Thermal flexibility forecasting, Proactive Demand Reshaping, and Grid-support (stability) management.

The main RES system already installed in DUTh's students' residences is a hybrid system that utilizes a biomass boiler and a solar thermal system for heating, cooling, and domestic hot water, and it supports the whole building complex. Figure 25 presents the simplified one-line diagram of the hybrid system. The main components of the system include 740 selective flat plate solar collectors of 2.58 m^2 each, 4 solar stations with plate heat exchangers, one biomass boiler of 1.15 MW_{th}, an underground metallic biomass storage tank of 35 m^3, an absorption chiller of 316.52 kW_c coupled with a cooling tower of 720.5 kW and 4 outdoor hot water tanks of 10 m^3 each. The solar field consists of 4 identical solar collectors' loops. Each loop consists of 40 parallel solar strings with 4 or 5 collectors. A "reverse-return" connection is selected to achieve hydraulic balance. Solar collectors are supported by an aluminum system that utilizes trembling. Each loop is controlled by a specific solar station that utilizes speed variation to maintain a stable ΔT between the solar collectors and the thermal energy storage (TES) system. Water/glycol mixture is a heat transfer medium to prevent freezing conditions. The solar field of the present demo includes flat plate collectors coupled with four thermal storage tanks (10 m^3 each). A biomass-fueled boiler aligns with the previous system, which provides extra thermal energy to achieve a temperature level of 75°C before delivering hot water to the buildings.

In building C1, 5,5 m^3 of TES are utilized as a percentage of the total 40 m^3 integrated with the hybrid solar and biomass systems. Inside building C1, radiators are applied as terminal units to distribute space heating to the rooms, as is the case for all dormitory buildings of the complex. A 2 m^3 auxiliary water storage tank stores hot water to cover the building's DHW needs. The DHW tank also includes a thermal resistance of 9 kW to increase the hot water temperature if the University's (local) district heating network does not satisfy the desired temperature threshold. The DHW temperature set point of 45°C and the occupants' specific daily demand of 50 L per person are selected according to Greek legalization.

The resistance's schedule is divided into three 2-hour operation periods (07:00-09:00, 14:00-16:00, and 20:00-22:00).

The renovation process at the Pilot Site's "Building C1" will involve several key interventions to improve energy efficiency and integrate renewable energy systems. These include monitoring 20 rooms, connecting a geothermal field and absorption chiller to Building C1, and upgrading the piping insulation and hydraulic grid. Additional enhancements will include the installation of circulation and recirculating pumps for domestic hot water (DHW), expanding the Building Management System (BMS), and incorporating a bifacial photovoltaic (PV) system. Furthermore, an inverter for the Organic Rankine Cycle (ORC) engine will be introduced, along with new fan coils for heating and cooling, increased thermal energy storage (TES) capacity, and two electric vehicle (EV) chargers. The project also emphasizes the preparation of tenders to ensure timely implementation to select contractors by January 2025.

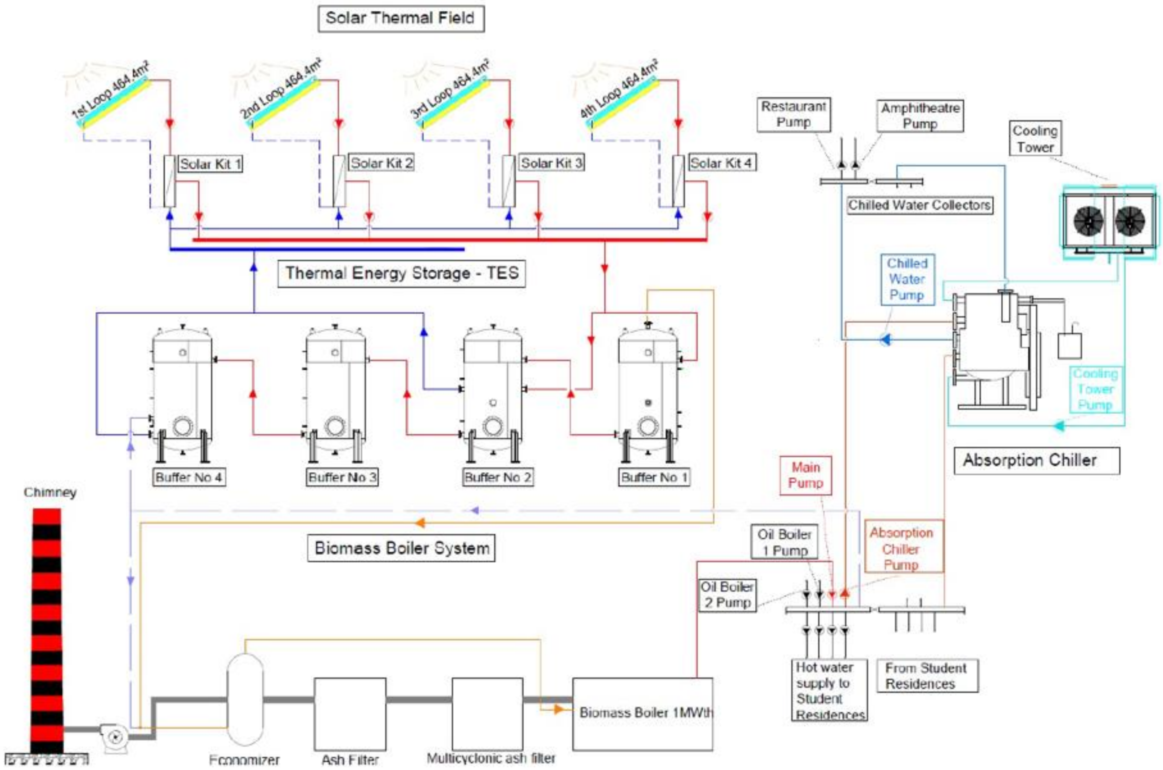

Figure 25: Simplified overview of the Pilot Site's existed hybrid (solar/biomass) thermal energy production system.

Within the framework of Tasks 2.1 and 2.3 CERTH has conducted detailed simulations regarding the energy performance of the Greek demo building prior to (baseline) and after the renovation. Results regarding the existing performance of the building are presented in this report, while the respective results for the renovation will be presented in D2.2.

Table 5 summarizes the building's annual energy demands expressed in kWh. The heating demand and the DHW demand were calculated at 215,000 kWh/y. The boiler energy demand in fuel was calculated at 170,976 kWh and the respective useful heat production from the boiler at 157,298 kWh. The energy demand coming from the electrical heaters was calculated at 69,737 kWh. When added to the electrical demand required for appliances, lighting, and auxiliary electrical energy input for DHW, the total energy demand to cover the electricity need of the building amounts to 139,468 kWh. The solar thermal field produces 43,450 kWh that are stored in Tank-1 and are used as renewable energy assistance for covering both space-heating and DHW demands. The auxiliary energy input was calculated at 7,133 kWh; a relatively low value that indicates that the FPC-Boiler system is able to produce the majority of the DHW demand. Additionally, the thermal energy losses of the tanks and the pipelines are included in this table. The distribution losses via the pipeline system are calculated at 16.7% of the

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building's heating and DHW energy demand approximately that is considered a reasonable value.

Basic demands	
Parameters	*Values (kWh)*
Heating Energy Load and Energy demand for DHW	215,000
Boiler energy demand in fuel	170,976
Auxiliary electrical energy input for DHW	7,133
Electrical Energy for appliances and lighting	62,598
Electrical Energy for electric heaters	69,737
Total Electrical Energy Demand	139,468
Other important energy quantities	
Parameters	*Values (kWh)*
Boiler useful thermal energy production	157,298
Useful collector thermal energy production	43,450
Available solar energy on the solar field	425,043
Thermal losses	
Parameters	*Values (kWh)*
Tank-1	3,611
Tank-2	2,598
Pipeline system	27,646

Table 5. Summary of the current C1 building's energy demand in kWh

A heat absorption chiller with nominal capacity 316 kW_c is also installed. This system is powered by the excess thermal energy of the solar thermal park and currently is not interconnected with the C1 building as there is currently no piping network. There is also a geothermal field of thirty boreholes with a depth of ninety meters each which is also not interconnected with the C1 building. Via suitable interconnection the last two energy systems could supply primary energy to the multi-source heat pump to cover heating and cooling needs of the rooms of the examined building.

2.2.3.2 Methodology considered for the assessment of the demo site condition

For the Greek Demo at the Democritus University of Thrace (DUTH) Campus, the project team thoroughly evaluated the operation and energy usage of the hybrid renewable energy system in "Building C1" on-site in collaboration with the university's facility management and maintenance contractors. In alignment with improving energy security, the current renewable energy system infrastructure will be optimized, and a new Psyctotherm heat pump will be proposed for integration. This addition will further enhance the system's ability to provide reliable heating and cooling, leveraging the existing absorption chiller, geothermal heat, solar thermal, and biomass boiler systems to maximize energy efficiency. Integrating Bi-Facial PVs and utilizing the ORC turbine to provide electricity in Building C1 will also increase energy efficiency.

RENEL, with the specialized insulation approach, will enhance the building's thermal performance and reduce overall energy consumption. These improvements will be incorporated into the design and tender documents for the upcoming system upgrades. The C1 building is constructed with a concrete bearing body and brick walls and is poorly insulated (estimated average U=1 W/m^{2}K). The glazing consists of aluminum double-glazed windows with poor airtightness (estimated average Uw>4W/m^{2}K) and the roof is concrete covered with tiles and inclined.

Furthermore, the monitoring infrastructure is being significantly enhanced to gain deeper insights into the behavior of the building's residents and provide more accurate energy management data. This includes the installation of advanced sensors and monitoring devices, such as calorimeters and additional temperature probes in the solar collector loops and the biomass boiler system. These upgrades will improve the system's operation's accuracy and provide a better understanding of occupancy patterns and energy use, allowing for more tailored energy services.

The process used to evaluate the demo site's condition involved a well-organized and detailed approach, using a mix of both qualitative and quantitative methods. Normally, this type of assessment starts with a close look at the site's current state, which includes going over architectural plans, historical records, and any previous evaluations. This initial step was important for getting a clear picture of the site's baseline condition, spotting any existing problems, and setting the stage for further analysis. The approach also included discussions with key stakeholders, on-site visits, and the use of various diagnostic tools to gather data on how the site is currently performing.

On April 18, 2024, the initial pilot visit was held in Kimmeria, Xanthi. The site was attended by three SEEDS partners: CERTH, RENEL, and DUTH. The agenda included a direct tour of the area, an evaluation of the current pilot conditions and the monitoring/automation systems in place, and a comprehensive discussion about the equipment to be installed at the pilot site.

In more detail, after surveying the pilot site the following information has been retrieved leading to the following suggestions for improving energy efficiency, demand response and smart readiness.

Network Infrastructure: The C1 building features a central server rack and provides a stable wireless internet connection throughout all rooms. Unlike conventional setups, it lacks ethernet ports in individual rooms, promoting a wireless-first approach. The building is

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equipped with a management system that tracks historical data on energy, thermal consumption, and water supply, offering valuable insights for efficient resource management. Remote access to the building's internal network will be available, enabling off-site management and monitoring for optimal conditions and troubleshooting.

Environmental Monitoring: A meteorological station on-site will track environmental conditions, enhancing the automation IoT platform's smart capabilities.

IoT Integration: Sensors will connect wirelessly via Z-Wave or LoRaWAN protocols to MQTT gateways. This wireless system will be designed for scalability and security to meet the building's needs.

Room Automation: Each of the 20 rooms will be equipped with a Raspberry Pi gateway, a smart calorimeter, a multi-sensor for temperature, CO_2, and humidity, and a wireless electric smart meter. These devices will work together to deliver seamless and intelligent room automation.

Climate Control: Temperature regulation will be managed by 230 V fan coils with simple ON/OFF controls and 3-way valves with sensors for precise temperature management. A 70 kW heat pump will provide both cooling and heating, adapting to seasonal changes.

Energy Generation: The building will utilize solar energy through bi-facial photovoltaic (PV) panels, which feature dual-axis reflectors to maximize sunlight capture. The estimated installed capacity for these PV panels is around 10 kW. They will be paired with a smart inverter system for efficient energy conversion and reflector controllers to optimize energy yield and efficiency.

Electric Vehicle Support: EV chargers adhering to the IEC 61851 protocol will be installed, equipped with remote control capabilities for flexible charging schedules. In addition, an SRI assessment was carried out to report on the current Smart Readiness scores for the Greek pilot (before applying any improvements to the pilot building), shown in the following figures (Figure 26 and Figure 27 respectively).

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TOTAL SRI SCORE	7.2%	SRI CLAS Lower than 20%

IMPACT SCORES

Energy efficiency	17.7%
Energy flexibility and storage	9.7%
Comfort	0.0%
Convenience	12.5%
Health, well-being and accessibility	0.0%
Maintenance and fault prediction	0.0%
Information to occupants	0.0%

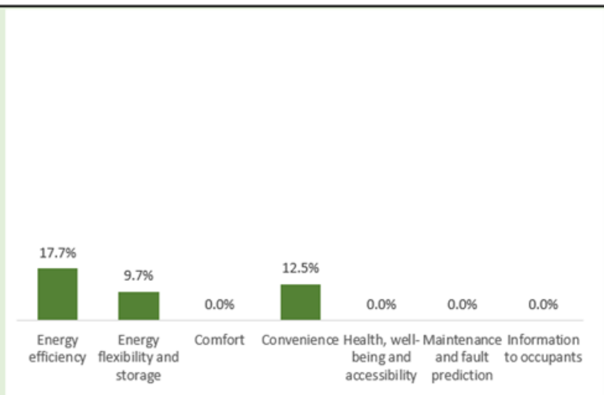
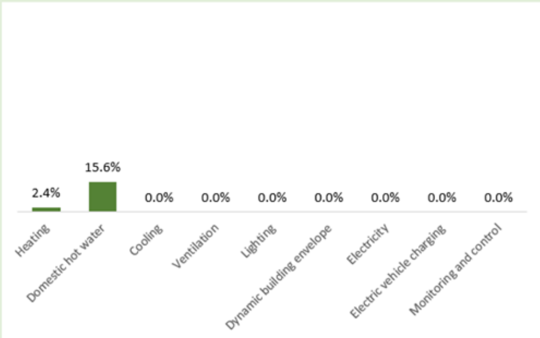


Figure 26: Smart Readiness Indicator (SRI) of Building C1 before applying any improvements (Total SRI Score and Impact Scores)

DOMAIN SCORES

Heating	2.4%
Domestic hot water	15.6%
Cooling	0.0%
Ventilation	0.0%
Lighting	0.0%
Dynamic building envelope	0.0%
Electricity	0.0%
Electric vehicle charging	0.0%
Monitoring and control	0.0%



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	14.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Domestic hot water	27.3%	18.2%	0.0%	28.6%	0.0%	0.0%	0.0%
Cooling	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ventilation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Lighting	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Dynamic building envelope	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Electric vehicle charging	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Monitoring and control	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

AGGREGATED SCORES

Key functionality 1 - building	8.9%
Key functionality 2 - user	3.1%
Key functionality 3 - grid	9.7%

Figure 27: Smart Readiness Indicator (SRI) of Building C1 before applying any improvements (Domain, Detailed and Aggregated Scores)

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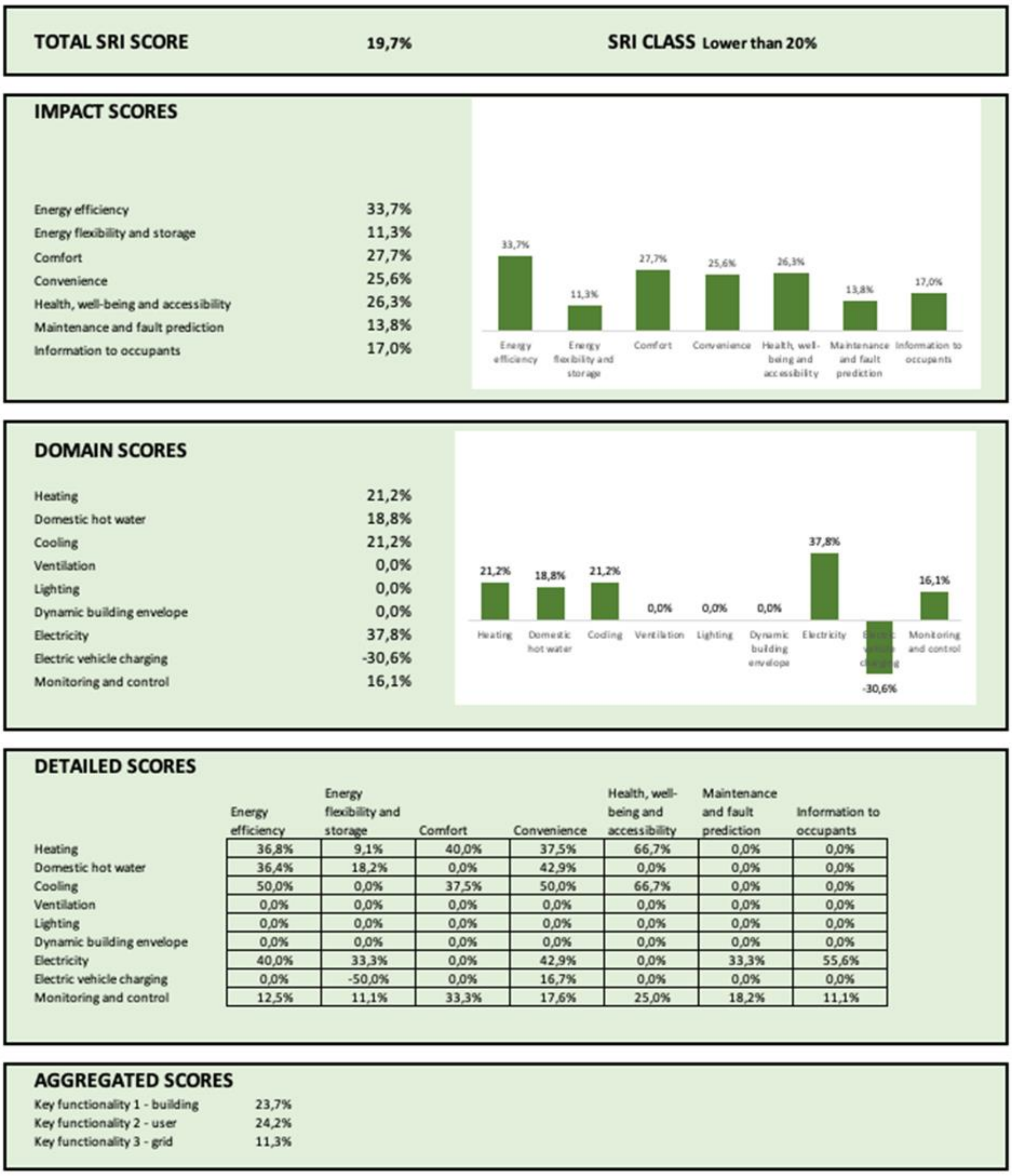
2.2.3.3 Detailed technical analysis based on the implementation tool

Another assessment will be carried out after integrating all foreseen improvements to the building. Thus, the foreseen SRI assessment results will be improved as depicted in the following figures.



TOTAL SRI SCORE	19,7%	SRI CLASS Lower than 20%

IMPACT SCORES

Energy efficiency	33,7%
Energy flexibility and storage	11,3%
Comfort	27,7%
Convenience	25,6%
Health, well-being and accessibility	26,3%
Maintenance and fault prediction	13,8%
Information to occupants	17,0%

DOMAIN SCORES

Heating	21,2%
Domestic hot water	18,8%
Cooling	21,2%
Ventilation	0,0%
Lighting	0,0%
Dynamic building envelope	0,0%
Electricity	37,8%
Electric vehicle charging	-30,6%
Monitoring and control	16,1%

DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	36,8%	9,1%	40,0%	37,5%	66,7%	0,0%	0,0%
Domestic hot water	36,4%	18,2%	0,0%	42,9%	0,0%	0,0%	0,0%
Cooling	50,0%	0,0%	37,5%	50,0%	66,7%	0,0%	0,0%
Ventilation	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Lighting	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Dynamic building envelope	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electricity	40,0%	33,3%	0,0%	42,9%	0,0%	33,3%	55,6%
Electric vehicle charging	0,0%	-50,0%	0,0%	16,7%	0,0%	0,0%	0,0%
Monitoring and control	12,5%	11,1%	33,3%	17,6%	25,0%	18,2%	11,1%

AGGREGATED SCORES

Key functionality 1 - building	23,7%
Key functionality 2 - user	24,2%
Key functionality 3 - grid	11,3%

Figure 28: Smart Readiness Indicator (SRI) of Building C1 after integrating the foreseen improvements

The figure provides an overview of the building's Smart Readiness Indicator (SRI) score, revealing several important aspects related to energy efficiency, comfort, and smart features. With a **total SRI score of 19.7%,** the building falls into a category below 20%, indicating that its smart readiness is fairly low. The impact scores highlight that the building performs reasonably well in energy efficiency (33.7%) and comfort (27.7%), but scores significantly lower in areas such as energy flexibility and storage (11.3%) and occupant information (17.0%). Of particular concern is the negative score for electric vehicle charging (-30.6%), which has a considerable impact on the overall performance and suggests the need for major improvements in this area.

Looking at the domain scores, the building performs moderately well in heating (21.2%) and electricity (37.8%), but poorly in dynamic building envelope (0.0%) and ventilation (0.0%), both of which are crucial for enhancing energy efficiency and comfort. Detailed scores show that while some areas, like heating and domestic hot water, have acceptable energy efficiency, there is a total absence of functionality in ventilation and lighting. Aggregated scores further underline that the building's key functionalities, especially for grid integration (11.3%), are underdeveloped. This assessment suggests that the building needs significant upgrades, particularly in areas like electric vehicle charging, ventilation, and dynamic building envelope, to improve its smart readiness.

2.2.3.4 Evaluation results and identification of areas for improvement

The SRI score before integration was quite low (7.2%), reflecting a limited adoption of smart technologies. After improvements, there was a noticeable increase in the SRI score (19.7%), indicating significant advancements in several key areas.

In more detail regarding **Impact Scores**:

- **Energy Efficiency**: Improved from 17.7% to 33.7%. This indicates that significant energy efficiency measures were introduced, likely including better HVAC systems, insulation, or energy management systems.
- **Energy Flexibility and Storage**: Increased from 9.7% to 11.3%, suggesting improvements in the building's ability to manage and store energy, possibly through renewable energy integration or battery storage.
- **Comfort**: Initially at 0%, this score jumped to 27.7%. This improvement could be due to enhanced HVAC systems, better insulation, or smart control systems that allow occupants to adjust comfort settings more effectively.
- **Convenience**: The score improved from 12.5% to 25.8%, likely reflecting the implementation of smart automation systems that make the building more user-friendly.
- **Health, Well-being, and Accessibility**: Increased from 0% to 26.3%. This suggests that the building was upgraded with features that improve air quality, lighting, and accessibility for individuals with disabilities.
- **Maintenance and Fault Prediction**: This was previously at 0% but improved to 13.8%. It indicates the integration of predictive maintenance technologies, reducing downtime and improving system reliability.

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- **Information to Occupants**: Improved from 0% to 17.0%, showing that systems were implemented to provide occupants with better information about energy usage, indoor environment quality, and other factors.

Regarding **Domain Scores**:

- Significant improvements were observed in **heating, domestic hot water, and cooling systems**. In particular, heating improved from 2.4% to 21.2%, domestic hot water from 15.6% to 21.1%, and cooling from 0% to 21.8%, showing that new or improved heating-cooling system(s) will be installed.
- **Ventilation**, **Lighting,** and **Dynamic Building Envelope** remain at 0%.
- **Electricity** jumped from 0% to 37.8% indicating drastic improvements in this domain.
- **Electric Vehicle Charging** went from 0% to -30.6%.
- **Monitoring and Control**: The increase to 16.1% suggests that the building now has better systems for monitoring energy use and controlling various systems, enhancing overall efficiency and user control.

Regarding **Key Functionalities**:

- **Key Functionality 1 - Building** improved from 8.9% to 23.9%, indicating better integration of smart features that enhance the building's operational performance.
- **Key Functionality 2 - User** improved from 3.1% to 21.4%, reflecting enhanced user interaction with building systems, likely through more intuitive controls or better information dissemination.
- **Key Functionality 3 - Grid** improved from 9.7% to 11.9%, showing modest improvements in how the building interacts with the electrical grid, possibly through demand response features or energy storage.

All in all, the pilot building underwent significant improvements, enhancing its functionality, energy efficiency, and overall user experience. Even after the improvements the SRI assessment suggests that the building needs significant upgrades, particularly in areas like electric vehicle charging, ventilation, and dynamic building envelope, to improve its smart readiness. However, while substantial progress was made, there remains room for further enhancement to fully optimize the building's capabilities. Future improvements should target the less developed areas to boost overall performance and smart readiness.

Current Performance Overview:

The Smart Readiness Indicator (SRI) for Building C1 at the DUTH Campus reveals a total score of 22.4%, placing the building in the SRI Class of "Between 20% and 35%." While the building demonstrates some level of smart readiness, there is considerable potential for improvement, particularly in areas critical to energy efficiency, flexibility, occupant comfort, and system reliability.

Key Areas for Enhancement:

1. Energy Efficiency:

Current Status: The building scored 31.2% in energy efficiency, indicating moderate energy-saving features.

Suggested Improvement: To enhance energy security and optimize the use of renewable energy sources, a Psyctotherm heat pump will be integrated into the existing hybrid system. This will complement the biomass boiler and solar thermal systems, providing a more consistent and efficient energy supply, especially during peak demand.

2. Energy Flexibility and Storage:

Current Status: The low score of 13.3% highlights a significant gap in the building's ability to manage energy flexibility.

Suggested Improvement: Implement energy storage solutions, such as batteries, and enhance demand response capabilities to improve the building's energy flexibility. These systems will allow better energy supply and demand management, reducing reliance on external sources and increasing resilience.

3. Comfort and Convenience:

Current Status: Comfort scored 39.8% and convenience 28.8%, indicating moderate occupant satisfaction but with room for improvement.

Suggested Improvement: Further refining the energy management system and expanding its control over HVAC operations could optimize temperature regulation and air quality, enhancing residents' comfort and convenience. Additionally, the building's ventilation and lighting systems should be upgraded to smart systems that adjust automatically based on occupancy and natural light conditions.

4. Health, Well-being, and Accessibility:

Current Status: This area scored 41.7%, the highest among impact scores, reflecting a strong focus on occupant health and accessibility.

Suggested Improvement: Continue to prioritize this area by ensuring that all upgrades, such as introducing a heat pump and maintain or enhance the building's ability to support occupant well-being.

5. Maintenance and Fault Prediction:

Current Status: The building scored 12.7% in this category, indicating limited predictive maintenance capabilities.

Suggested Improvement: Implement advanced monitoring and diagnostic tools to detect faults early and predict maintenance needs. This will improve system reliability and reduce the likelihood of unexpected failures, contributing to a more efficient and secure energy system.

6. Information to Occupants:

Current Status: With a score of 17.4%, minimal information is provided to occupants regarding energy use and system performance.

Suggested Improvement: Develop and deploy a comprehensive information system that provides residents with real-time data about their energy consumption, environmental conditions, and system performance. This could lead to more informed energy use behaviors and increased occupant engagement.

7. Monitoring and Control Systems:

Current Status: With a score of 16.1%, the building's monitoring and control systems are functional but limited in scope.

Suggested Improvement: Expand the scope of monitoring and control to include more granular data on energy use, system performance, and occupant behavior. This will support more accurate calibration of the energy monitoring and use and enable continuous improvement in energy management.

Strategic Implementation

To enhance the Smart Readiness of 'Building C1', the immediate focus should be on integrating the Psyctotherm heat pump to improve energy efficiency and security. Piping insulation along with the inverter main pump, bifacial PVs, and the integration of ORC-generated electricity for the energy center will enhance the efficiency of Building C1. In addition, geothermal field-generated heat and absorption chiller-generated cooling will be integrated with Psyctotherm's Heat Pump installation. Also, 20 fan coil units will be installed in Building C1 to cover both heating and cooling demands as terminal units. Concurrently, monitoring systems should be expanded to detect faults better and collect detailed performance data. Mid-term efforts should prioritize the development of a comprehensive information system for occupants and address the inefficiencies in the EV charging infrastructure. In the long term, continuous refinement of the energy delivery system and introduction of energy storage solutions will further enhance system resilience and flexibility, contributing to a higher overall SRI score.

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2.2.4 Slovenian Pilot

2.2.4.1 Description of the demo site

The Slovenian pilot consists of 5 gas stations, namely Gas station Izola, Bled, Čatež, Velenje and Celje. Three gas stations out of five are located on the area of Elektro Celje (DSO and consortium partner in SEEDS) and the two of them are spread at the different parts of Slovenia. The core project activities are focused on the remote management of the energy flexibility for the needs of further optimization of the energy consumption and in addition to that, our goal is also to offer flexibility services to the DSOs and TSO. In the previous period we have assessed the actual energy status of each gas station and have listed the existing and needed equipment and flexibility potential of that equipment.

Each of the listed locations has the energy sources and consumers as described in the following table (Table 6):

Location	GS Izola	GS Bled	GS Čatež	GS Velenje	GS Celje
External lighting	Yes	Yes	Yes	Yes	Yes
Internal lighting	Yes	Yes	Yes	Yes	Yes
Heat pump internal heating and cooling	Yes	Yes	Currently no but Planned	Currently no but Planned	Currently no but Planned
HVAC Split-systems	Yes	Yes	Yes	Yes	Yes
Ventilation devices	Yes	Yes	Yes	Yes	Yes
Heat pump – sanitary water	Yes	Yes	Yes	Currently no but Planned	Yes
Photovoltaic power plant	Yes	Yes	Currently no but Planned	Yes	Yes
Car wash	Yes - Manual	Yes - Manual	No	Yes - Automatic	No
Car wash – heated water with a heat pump	Currently no but Planned	Currently no but Planned	-	-	-
Car wash – floor heating	No	Yes	-	Yes	-
Electric heating of gutters	No	Yes	Yes	Yes	Yes
Electric vehicle charging station	No	Yes	Yes	No	Yes
Battery storage	No	No	Currently no but Planned	No	No
Diesel generator	No	No	Yes	Yes	No

Table 6: Slovenian Pilot - Energy sources and consumers matrix of 5 gas stations

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The GPS coordinates of the gas stations are listed in the table below (

Table 7: Gas stations' coordinates

):

Name of the Gas Station	Address	Latitude	Longitude	www
Gas Station Bled-Seliška	Seliška cesta 4c, 4260 Bled	46.370163	14.116395	BS BLED - SELIŠKA | Petrol
Gas Station Izola - Industrijska	Industrijska cesta 9B, 6310 Izola	45.535631	13.671735	BS IZOLA, INDUSTRIJSKA | Petrol
Gas Station Velenje - Celjska Vzhod	Celjska cesta 53, 3320 Velenje	46.350795	15.13198	BS VELENJE - CELJSKA VZHOD | Petrol
Gas Station Čatež AC - Jug	Rimska cesta 11, 8250 Brežice	45.8919043	15.59760745	BS ČATEŽ AC - JUG | Petrol
Gas Station Celje - Mariborska	Mariborska cesta 21, 3000 Maribor	46.23544773	15.27027173	BS CELJE - MARIBORSKA | Petrol

Table 7: Gas stations' coordinates

The following paragraphs present the selected pilot sites.

Gas station "Bled"

Figure 29: Gas station Bled

It was built in 2019, and the PV plant was installed in 2022. The gas station consists of the main gas station building, gas pumps under a separate covered area on one side of the building and a manual car wash located across a parking lot on the other side of the main building. Main building contains the shop area, food corner, storage, toilets, communication equipment room, boiler room and a separate bar area which is rented out to a bar business owner. The bar has its own electrical meter (kilowatt-hour meter) and a distribution box. The bar is not included in the pilot.

The main gas station building is already partially managed by POL648.80 (PETROL TP09) controller. The equipment that is not fully monitored and automated should be upgraded in a way that enables automated control of energy flows in the building. Manual car wash uses oil boiler for water heating a will be upgraded with a heat pump that will satisfy the monitoring and automation requirements. Existing photovoltaic power plant on the roof of the gas station will be included into energy management system.

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Gas station “Izola”

Gas station “Izola” was built in 2015 and had a PV power plant added in 2022. The gas station location consists of the main gas station building, gas pumps under a separate covered area on one side of the building and a manual car wash located across a parking lot on the other side of the main building. Main building contains the shop area, food corner, storage, toilets, communication equipment room, boiler room and a separate bar area which is rented out to a bar business owner.

Figure 30: Gas station Izola

The bar has its own electrical meter (kilowatt-hour meter) and a distribution box. The bar is not included in the pilot. The main gas station building doesn’t have an automated building management system. Manual car wash uses oil boiler for water heating a will be upgraded with a heat pump that will satisfy the monitoring and automation requirements. Existing photovoltaic power plant on the roof of the gas station will be included into the energy management system.

Gas station “Čatež”

Figure 31: Gas station Čatež

Gas station was built in 2004 and is located on the highway. The gas station location consists of the main gas station building, with a shop area on the left and a restaurant area on the right side of the building. The area of the gas station includes a shop area, storage, toilets, a communication equipment room, a boiler room.

The location has two electric vehicle charging stations (2 x 50 kW). It is planned to add two more charging stations in the coming years. The main gas station building doesn't have an automated building management system. There is currently no photovoltaic power plant, but one will be added in 2024 or 2025. In addition to photovoltaics, the integration of a battery storage system is planned. Heating is currently provided by liquefied petroleum gas (LPG), while hot water preparation is primarily done using a heat pump. We want to switch heating to a heat pump. The heating with LPG will remain in place and is intended to operate during colder temperatures and offering flexibility.

A separate restaurant area is rented out. The restaurant has its own electrical meter (kilowatt-hour meter) and a distribution box. The restaurant is not included in the pilot.

Gas station "Velenje"

Figure 32: Gas station Velenje

Gas station Velenje has been built in 1997 and is located on the main road between the highway and the city of Velenje. The gas station location consists of the main gas station building, with an automated manual car wash located near the main building. The area of the gas station includes a shop area, storage, toilets, a communication equipment room, a boiler room. The main gas station building doesn't have an automated building management system. The equipment should be upgraded in a way that enables automated control of energy flows in the building.

The existing photovoltaic power plant on the roof of the gas station will be included into the energy management system. Heating is currently provided by heating oil, while hot water preparation is done using electric heaters. We want to switch the heating and the preparation of hot water to a heat pump.

Gas station "Celje"

Gas station Celje has been built in 2007 and is a town gas station. The gas station location consists of the main gas station building, gas pumps under a separate covered area on one side of the building. Main building contains the shop area, food corner, storage, toilets, communication equipment room, boiler room and a separate bar area which is rented out to a bar business owner. The main gas station building doesn't have an automated building management system.

Existing photovoltaic power plant on the roof of the gas station will be included into the energy management system. Heating is currently provided by a roof-top heating machine on a natural gas., while hot water preparation is done using a heat pump. We want to switch the heating to a heat pump.

Figure 33: Gas station Celje

2.2.4.2 Methodology considered for the assessment of the demo site condition

In designing solutions for providing flexibility in electricity consumption at gas stations, we have relied on **historical data about the energy use of existing facilities**. We have extensive data on total energy consumption for selected gas station locations, and for the gas station in Bled, we also have more detailed data on the energy use of individual devices within the facility. This data includes historical consumption data over a period of 3-4 years.

A detailed analysis of this data has allowed us to identify devices whose operation can be adjusted to provide flexibility services. This is especially important when identifying actual and new devices that are suitable for integration into electrical grid flexibility systems, as their control can contribute to better alignment with grid loads and greater system stability.

Based on the analysed data, a project brief has been prepared for the designer, focusing on integrating existing and newly planned devices or systems in a way that ensures sufficient information from sensor and meters for effective regulation of controlled devices. The design will involve developing strategies for optimizing device operation and their interactions with the electrical grid, contributing to improved energy flexibility at the gas station.

By incorporating advanced technologies for monitoring and controlling energy consumption, the gas station will be able to better manage loads and contribute to the stability and efficiency of the electrical grid, which is crucial for supporting the sustainable development of energy infrastructure.

As part of the project, we will also test energy storage battery systems, which will contribute to further stabilizing the grid and enable the use of surplus generated energy on-site from solar panels. The systems and operational models will need to be tested and adjusted to support various energy usage modes, including the integration and deactivation of loads and storage units.

We are reviewing the calculation for the SRI classification for actual gas stations.

Our focus in the project is on creating a methodology for offering energy flexibility services to various market players. These services play a crucial role in enhancing grid stability but come with challenges such as dynamic resource allocation, aggregation, adherence to controllers, and collaboration among numerous stakeholders including electricity markets, aggregators, distribution and transmission system operators, and consumers. To address these complexities, we will employ advanced techniques like machine learning for predicting the state of flexibility resources and multi-criteria decision modelling to identify and aggregate their essential properties based on stakeholders' expertise. These aggregated criteria will be utilized in effective optimization algorithms that prepare flexible resources for market offering, ensuring a transparent and efficient energy trading process. The solution will undergo testing at the Slovenian pilot site alongside Petrol d.d. and Elektro Celje d.d., paving the way for large-scale implementation of these services.

2.2.4.3 Detailed technical analysis based on the implementation tool

All technological devices that will ensure flexibility at the facility are connected to the PETROL TP09 PLC via appropriate communication or signal protocols. The PLC will be integrated into the system as a master controller, which will take care of optimal control based on online measurements (e.g. temperature measurement etc.) and various input parameters (required references from other subsystems). Measurements on PLC are in online mode, which means that the data is constantly available and the pooling time from PLC to SCADA system is practically every second. A visual display of the data is displayed on the SCADA screen and is refreshed every second.

The exact list of measurements will be determined during the project design phase, but mostly they are the **measurements** as:

- temperatures and pressure in the boiler system;
- operating statuses of circulation pumps, valves, heat pumps, etc.;
- room temperatures;

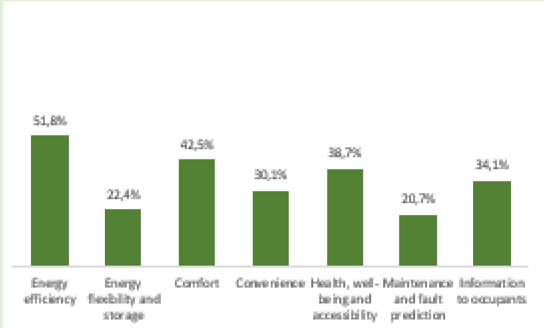
- measurements from heat counters and water counters including energy, flow and power;
- measurements from electrical counters including energy, voltage, current and power.

The first SRI assessment was carried out for gas station Bled-Seliška pilot site. Other locations which are part of the Slovenian Pilot will be carried out successively as the project progresses.

TOTAL SRI SCORE 31,7% SRI CLAS Between 20% and 35%

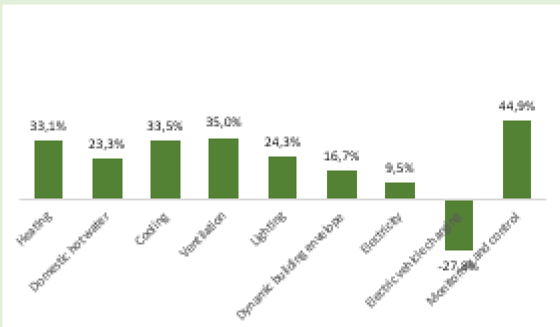
IMPACT SCORES

Energy efficiency	51,8%
Energy flexibility and storage	22,4%
Comfort	42,5%
Convenience	30,1%
Health, well being and accessibility	38,7%
Maintenance and fault prediction	20,7%
Information to occupants	34,1%



DOMAIN SCORES

Heating	33,1%
Domestic hot water	23,3%
Cooling	33,5%
Ventilation	35,0%
Lighting	24,3%
Dynamic building envelope	16,7%
Electricity	9,5%
Electric vehicle charging	-27,8%
Monitoring and control	44,9%



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	55,6%	12,5%	50,0%	36,4%	60,0%	20,0%	50,0%
Domestic hot water	33,3%	0,0%	0,0%	0,0%	0,0%	50,0%	66,7%
Cooling	57,9%	12,5%	50,0%	36,4%	60,0%	20,0%	50,0%
Ventilation	57,1%	0,0%	70,0%	62,5%	33,3%	0,0%	0,0%
Lighting	28,3%	0,0%	24,0%	24,0%	16,7%	0,0%	0,0%
Dynamic building envelope	0,0%	0,0%	0,0%	0,0%	0,0%	50,0%	33,3%
Electricity	14,3%	0,0%	0,0%	0,0%	0,0%	16,7%	33,3%
Electric vehicle charging	0,0%	-50,0%	0,0%	33,3%	0,0%	0,0%	0,0%
Monitoring and control	52,6%	66,7%	7,0%	36,5%	50,0%	20,1%	33,3%

AGGREGATED SCORES

Key functionality 1 - building	36,2%
Key functionality 2 - user	36,4%
Key functionality 3 - grid	22,4%

Figure 34: Smart Readiness Indicator (SRI) for gas station Bled (before improvements)

The figures above provide an overview of the building's SRI score for gas station Bled, which also indicate the current state of the location and at the same time they imply what should be improved in terms of the overall energy performance.

After the implementation of improvements, we can observe key changes in provided areas, which are comparable to the previous data presented above.

Smart Readiness Indicator for Buildings

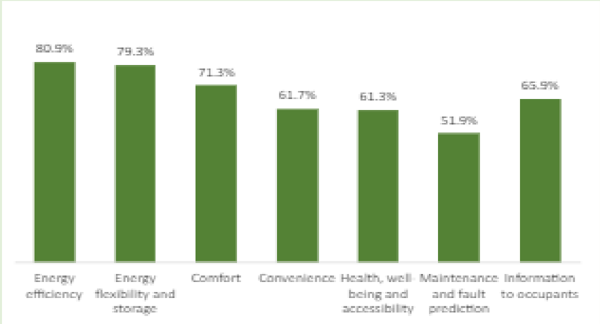
The SRI calculations have been performed with an experimental tool. Please note that the scores and the visual presentation of results are solely provided for testing purposes. Using this experimental tool can by no means lead to any claims on an actual score or certificate for a building.

SRI spreadsheet tool Version 4.5

TOTAL SRI SCORE	70.3%	SRI CLAS Between 65% and 80%

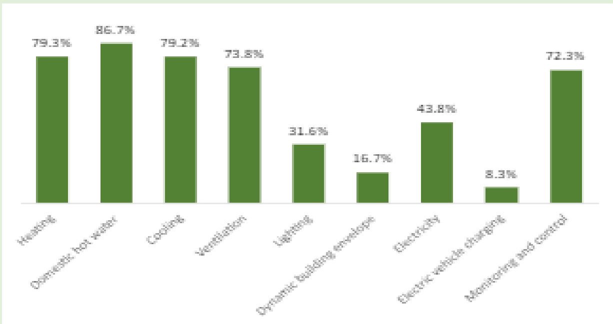
IMPACT SCORES

Energy efficiency	80.9%
Energy flexibility and storage	79.3%
Comfort	71.3%
Convenience	61.7%
Health, well-being and accessibility	61.3%
Maintenance and fault prediction	51.9%
Information to occupants	65.9%



DOMAIN SCORES

Heating	79.3%
Domestic hot water	86.7%
Cooling	79.2%
Ventilation	73.8%
Lighting	31.6%
Dynamic building envelope	16.7%
Electricity	43.8%
Electric vehicle charging	8.3%
Monitoring and control	72.3%



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DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	88.9%	75.0%	83.3%	90.9%	80.0%	60.0%	100.0%
Domestic hot water	100.0%	100.0%	0.0%	66.7%	0.0%	50.0%	100.0%
Cooling	89.5%	75.0%	90.0%	81.8%	80.0%	60.0%	100.0%
Ventilation	78.6%	0.0%	90.0%	87.5%	88.9%	50.0%	66.7%
Lighting	36.7%	0.0%	34.0%	34.0%	16.7%	0.0%	0.0%
Dynamic building envelope	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	33.3%
Electricity	42.9%	54.5%	0.0%	45.5%	0.0%	16.7%	55.6%
Electric vehicle charging	0.0%	0.0%	0.0%	50.0%	0.0%	0.0%	0.0%
Monitoring and control	79.4%	88.9%	78.3%	60.9%	50.0%	48.6%	66.7%

AGGREGATED SCORES

Key functionality 1 - building	66.4%
Key functionality 2 - user	65.1%
Key functionality 3 - grid	79.3%

Figure 35: Smart Readiness Indicator (SRI) for gas station Bled (after the improvements)

The SRI score before integration was **31.7%**. After improvements, there was a noticeable increase in the SRI score (**70.3%**) indicating significant advancements in several key areas. However, we must emphasize that the extent to which the changes will be implemented depends primarily on the budget that will be allocated to the project. In this context, the numbers (SRI score) could be higher or even significantly lower.

In more detail regarding **Impact Scores**:

- **Energy Efficiency**: Improved from 51.8% to 80.9%. This substantial increase suggests that effective energy efficiency measures have been implemented, likely involving upgrades to HVAC systems, enhanced insulation, or the introduction of advanced energy management systems. These improvements reflect a focused approach to reducing energy consumption and optimizing operational performance.
- **Energy Flexibility and Storage**: Increased from 22.4% to 79.3%. This notable enhancement indicates a strengthened capacity for energy management and storage, likely achieved through the integration of renewable energy sources or the deployment of battery storage solutions. Such improvements demonstrate an advanced approach to energy resilience, enabling greater adaptability and alignment with sustainable energy practices.
- **Comfort:** Elevated from an initial score of 42.5% to 71.3%. This marked improvement is likely attributable to advancements such as optimized HVAC systems, superior insulation, or the incorporation of intelligent control systems, enabling occupants to fine-tune comfort settings with greater precision. These enhancements foster a more refined and adaptive indoor environment.

- **Convenience**: Progressed from 30.1% to 61.7%, indicating a substantial boost in user accessibility and ease of operation, likely due to the deployment of sophisticated automation systems. These advancements create a more intuitive and seamless experience for occupants.
- **Health, Well-being, and Accessibility:** Rose from 38.7% to 61.3%, implying that enhancements were made to support air quality, lighting conditions, and accessible design for individuals with disabilities. These upgrades indicate a focus on creating a healthier, more inclusive environment within the building.
- **Maintenance and Fault Prediction**: Advanced from 20.7% to 51.9%, suggesting the incorporation of predictive maintenance solutions. This upgrade aids in reducing system interruptions and bolsters overall reliability by anticipating and addressing issues before they escalate.
- **Information to Occupants**: Enhanced from 34.1% to 65.9%, indicating the implementation of systems designed to deliver comprehensive information regarding energy consumption, indoor environmental quality, and additional relevant factors to occupants.

Regarding **Domain Scores**:

Remarkable advancements were noted in the heating, domestic hot water, and cooling systems. Specifically, heating efficiency increased from 33.1% to 79.3%, domestic hot water performance rose from 23.3% to 86.7%, and cooling systems saw an enhancement from 33.5% to 79.2%.

These upgrades are expected to positively influence several previously mentioned metrics. For instance, the enhanced heating system is likely to contribute to improved comfort levels, leading to a higher overall satisfaction score. The significant boost in domestic hot water performance can further enhance health, well-being, and accessibility by ensuring adequate hot water supply, thus supporting better hygiene and sanitation. Additionally, the improvements in cooling efficiency are anticipated to enhance energy efficiency and flexibility, as well as reduce operational costs, making the building more sustainable and user-friendly.

Regarding **Key Functionalities** the following can be observed:

- **Key Functionality 1 – Building:** The building's performance has risen from 36.2% to 66.4%, signifying enhanced integration of intelligent features that optimize operational effectiveness. This improvement is anticipated to positively impact energy efficiency scores by maximizing resource utilization and minimizing waste.
- **Key Functionality 2 – User:** User engagement with building systems has increased from 36.4% to 65.1%, indicating better usability, likely achieved through more intuitive controls and improved information sharing. This enhancement is expected

to elevate convenience scores, as occupants will find it easier to interact with systems, thereby enriching their overall experience.

- **Key Functionality 3 – Grid:** The building's relationship with the electrical grid has progressed from 22.4% to 79.3%, reflecting significant advancements in capabilities that enhance grid interaction, such as demand response mechanisms and energy storage options. These upgrades are likely to strengthen energy flexibility scores, enabling the building to adapt more effectively to grid requirements and fluctuations, ultimately fostering a more sustainable energy approach.

In summary, the pilot building (in Bled) demonstrated commendable performance prior to the recent enhancements, showcasing solid functionality, energy efficiency, and user experience scores. The substantial improvements made in key areas such as heating, domestic hot water, cooling systems, and the integration of smart technologies have further elevated these metrics, leading to significant increases in energy efficiency, comfort, and user interaction.

Despite these advancements, the Smart Readiness Indicator (SRI) assessment highlights that there are still considerable opportunities for growth. Areas such as electric vehicle charging infrastructure, ventilation systems, and a dynamic building envelope require additional focus to enhance the building's smart readiness.

While the improvements achieved are noteworthy, there remains potential for further upgrades to fully optimize the building's capabilities. Future efforts should concentrate on these underdeveloped aspects to continue boosting overall performance and ensure the building meets the evolving demands of users and sustainability standards

2.2.4.4 Evaluation results and identification of areas for improvement

The improvement areas based on the project's current state are presented in the following paragraphs.

1. **Energy Data and Device Monitoring:**

We need to expand detailed, device-level monitoring, similar to what has been implemented at the Bled gas station, to all other gas stations in the project. This will allow us to achieve more precise control over energy use and gather additional data to better assess flexibility potential.

2. **Device Integration and Control:**

It's essential to ensure seamless integration of all identified devices with the master controller (PLC), while also verifying compatibility between sensors/meters and various systems (e.g., boilers, pumps, heat pumps). Further testing of control strategies could help optimize the operation of these devices for providing flexibility services.

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3. **Energy Storage and Solar Panel Integration:**

We should evaluate whether the energy storage systems are appropriately sized for the specific needs of each gas station. Additionally, testing the integration of energy storage with flexible loads will be necessary to ensure that surplus energy from solar panels is efficiently utilized or stored.

4. **Prediction Models for Flexibility Resources:**

It will be important to regularly update the training datasets for our machine learning models with the latest data from all gas stations. Continuous monitoring of the accuracy and performance of these models under real-world conditions will help us improve predictions for resource flexibility and operational needs.

SCADA System and Communication Protocols:

We should assess the communication protocols between the PLC and SCADA system to reduce latency and improve data polling efficiency. Exploring options for automating certain controls and applying predictive strategies could allow for proactive, rather than reactive, adjustments to improve flexibility.

5. **Collaboration and Stakeholder Integration:**

Strengthening collaboration among market players (e.g., aggregators, grid operators, and other stakeholders) is key to ensuring smooth integration of flexibility services. Establishing regular feedback loops will help us align the project with evolving market conditions and regulations.

6. **Testing and Scalability:**

A broader range of testing scenarios will be necessary, particularly in different market environments, to identify any potential system bottlenecks or scalability challenges. Early identification of these issues will allow us to make adjustments before full implementation.

By addressing these areas, we can ensure that our project remains on track, providing robust, scalable solutions for enhancing grid flexibility and energy efficiency.

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3 INTEGRATED CIRCULAR DESIGN AND COST ASSESSMENT

3.1 EUROPEAN POLICIES RELATED TO CIRCULAR ECONOMY IN BUILDING SECTOR

Attaining the European goals about reducing carbon dioxide (CO_2) emissions by at least 55% until 2030 compared to 1990 levels and becoming a climate-neutral continent until 2050 are key priorities for the European Union (EU), implementing the commitments made under the Paris Agreement in 2015 [2], [3]. The aim of this Agreement was to strengthen the actions against the threat of climate change in the framework of sustainable development and alleviation of poverty [3].

In December 2019, the European Council along with the European Commission, established the European Green Deal, which is the EU's strategy to overcome the aforementioned challenges and implement the United Nation's 2030 sustainability targets. This strategic plan ensures a resource-efficient and competitive economy via eliminating the harmful emissions by 2050, reassuring economic growth irrespective of resource utilization and embracing a cohesion policy to empower both people and places towards sustainable development [4].

In order to deliver the economic, environmental and social objectives of the EU Green Deal it is highly important not only to implement new measures but also to reconsider existing policies and legislation and ensure that they are effectively implemented.

The energy sector is in the spotlight for the fulfilment of the 2030 and 2050 climate objectives. Clean energy technology deployment is to accelerate rapidly to reach the EU's climate goals and, therefore, energy from renewable sources and energy efficiency are the frontrunners for the energy transition. This specific section of the EU Green Deal also underlines the involvement of consumers in the transition as well as the necessity to address the risk of poverty for households that cannot afford special services via effective financing schemes. One final aspect of great importance is the development of spart infrastructure, such as energy storage, hydrogen networks, smart grids in order to achieve the ambitious goal of climate neutrality. Existing infrastructure could play a key role in the integration of renewables assuming that it is properly upgraded to fit to the new energy requirements [4].

In order to respond to considerable amounts of energy the building sector consumes, renovation actions, “renovation wave”, for public and private buildings was a priority for EU. According to the EU Green Deal, in 2020 the European Commission would launch an open platform to enable collaboration between the building and construction sectors as well as engineers and local authorities. The expected impact via that initiative was to promote energy efficiency investments on buildings, boost financing instrument developments and encourage renovation efforts into large blocks to benefit from economies of scale [4].

Figure 36 summarizes the main aspects of the Green Deal strategy [4].

Figure 36: The European Green Deal [4]

To address climate change, a shift from a linear economy to a circular is crucial. According to the United Nations, in 2022 62 million tons of e-waste were produced from electric and electronic devices worldwide [5] while it is estimated that 1.12 billion tons of waste is produced annually[6]. Various organizations and institutions are working towards achieving circular economy, including the EU.

3.1.1 Circular Economy Action Plan

Although transformation of the industrial sector is of the utmost importance to attain net zero emissions and a circular economy in 2050, there has been little progress towards this transition. Even though the construction industry consumes a great amount of energy and raw materials, only 40% of the construction waste is recycled or reused after the building's end of life and when materials are recycled, they are used for second-grade construction instead of new buildings [7].

In March 2020 the European Commission initiated an industrial strategy to enable the twin transition to climate neutrality and digital economy. Along with this policy a circular economy action plan (CEAP) was adopted to contribute to the modernization of EU's economy and the

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development of markets with low-emission technologies, sustainable products and services. This plan is one of the main building blocks of the European Green Deal and includes also a sustainable products strategy. The latter embraces reducing and reusing materials before recycling them, thus, new business models could be developed and harmful products would be banned from the market [4]. In May 2021 the strategy was updated in order to adapt to the new circumstances the COVID-19 pandemic caused. This strategic plan did not replace the 2020 industrial plan and focused mainly on needs and lessons learnt [8], [9].

The CEAP foresees the launch of a sustainable built environment strategy. The aim of this strategic plan is to increase material efficiency and promote circular principles during the life cycle of the buildings to reduce the climate impact of the built environment. The strategy embraces the development of digital logbooks for buildings, enhanced resilience, flexibility of constructed assets and the incorporation of life-cycle evaluation into public procurement as ways to promote circularity initiatives.

The objectives of the CEAP do not focus solely on the construction and building sector rather than making sustainability a norm for the EU Member States, including a plethora of areas with high circularity potential. To achieve this, the EC will implement a list of 35 actions, while it is essential to monitor the progress towards a circular economy. The monitoring framework, adopted since 2018 and revised in 2023, takes into account the material footprint and the resource productivity that will allow to monitor the material efficiency along with the consumption footprint to ensure that consumption is within the boundaries [10].

3.1.2 Waste Framework Directive

Statistics have shown that the average European citizen produces each year an average of 5 tons of waste. At the same time, **only 38% of the EU waste is being recycled** while over 60% of the EU household waste ends up in a landfill [11]. The waste policy set within the EU aims to protect both the environment and human health while at the same time supporting the EU's transition from a linear economy to a circular economy. The Waste Framework Directive (WFD) set the basic concepts and definition related to waste management, recycling and recovery. Its target is to support waste management without endangering human health or causing harm to the environment, including any potential risk to water, oil, soil, air, plants or animals. Places of special interest are also taken into account along with nuisance due to noise or odors. The WFD allows waste to be transformed to a secondary raw material in order to be reused while setting the end of waste criteria that specify when certain waste ceases to be waste becoming a product or a secondary raw material. The foundation of the EU waste management follows a five-step hierarchical process that aims at establishing as a first and preferred option the prevention of the waste and only as a last resort the disposal of the waste in landfills. The following figure (Figure 37) illustrates the order of preferred options for waste management.

Figure 37: Waste hierarchy of the WFD as the foundation of EU waste management [12]

3.2 COMMONLY USED CIRCULAR BUILDING STRATEGIES

The building sector is able to have a significant impact on the environment as the construction industry accounts for more than 30% of the greenhouse gas (GHG) emissions and 40% of the generated waste [13]. Taking into consideration that the existing sustainability strategies were not able to provide the much-needed impact, in conjunction with the lack of resources, the circular economy came as a necessity [14]. At the same time, natural resources are consumed during the buildings' lifetime and the construction industry is responsible for approximately 30% of the water use and the extraction of raw materials as well as 25% of solid waste generated worldwide [15].

As the building sector is considered a priority many models and principles have been proposed. One of the first circular economy related principles introduced the concept of the 3R's, "Reduce, Reuse, Recycle". Minimizing the inputs and outputs of raw materials and waste was described as "Reduce", the use of an existing product after reaching its end-of-life was described with the terms "Reuse", while the process of recovering waste to create a new product was described as "Recycle" [13]. This principle, however, needed to be expanded in order to include the extension of the products' lifespan and increase circularity in the product design. The extended principle also included "Refuse" and "Rethink" to describe the processes of proposing different products with a similar or better function and less impact to the environment, the adoption of smarter strategies and products with multiple functions while "Reduce" included the decrease of raw materials and energy consumption. Finally, the R-list was modified again to introduce the concepts of "Repair", "Refurbish", "Remanufacture", "Repurpose" and "Recover" [16].

Adopting **circular economy strategies** will allow to increase savings by creating proper systems that will retain the value and the resources flowing in a circular manner. This closed system will support the implementation of closed loops for various aspects of the buildings, including materials, components, energy and water, aiming to minimize the impact on the environment [17], [18]. This cycle includes processes that allow to select the proper materials, to define components that are able to be maintained extending therefore their lifetime as well as to support natural sources that are biodegradable and can be decomposed after their useful lifetime [19], [20]. The following figure (Figure 38) presents a closed loop system, where the use of the components and the materials is optimized aiming at retaining the highest value [13].

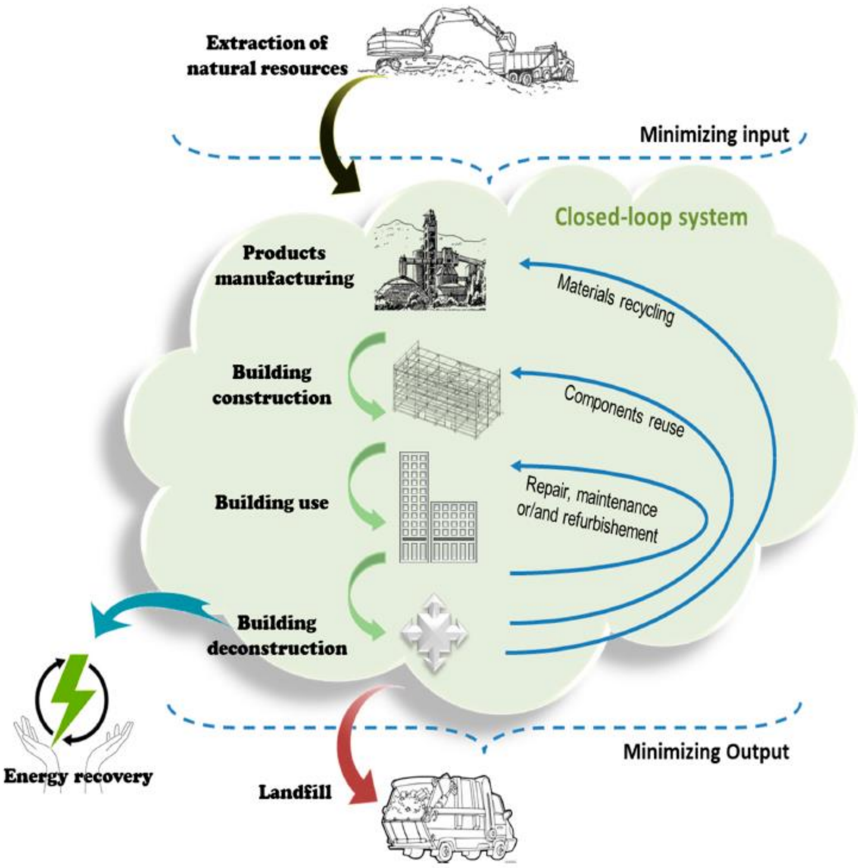

Figure 38: Closed loop materials and components in buildings [13]

However, in order to be able to move from a linear economy to a circular, the **circular economy principles** have to be applied to all phases of the buildings' lifecycle, introducing a proactive design approach that will manage the buildings from cradle to cradle. The following figure (Figure 39) presents the transition to circular economy based on the R's principles and the waste elimination.

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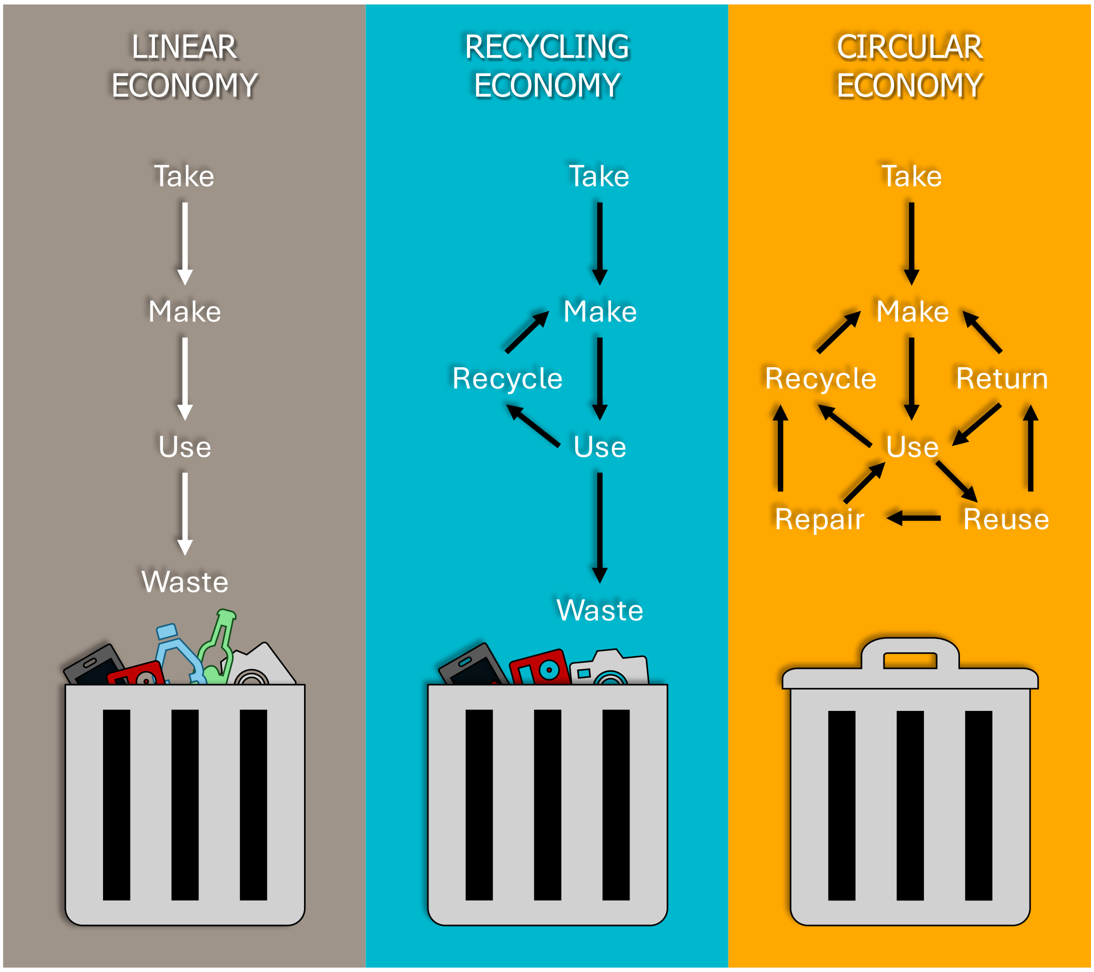

Figure 39: Linear to circular economy

Concerning the building sector, the circular economic principles have to be applied and implemented in all phases of the building's life. Starting from the product selection stage where locally available materials should be used, taking into account the reusability and the recovery of those materials, towards the end-of-life phase. In the end-of-life phase, proper training is required for the personnel to identify the building elements that could be salvaged to be reused in other applications, while the materials and the components should be separated to be sent to the proper waste management facilities. During the construction phase prefabricated construction is preferred and priority should be given to the modular nature of each component or system. Similar to the end-of-life phase, the personnel during the construction phase should be properly trained to implement the circular economy principles while ensuring that all the necessary safety procedures are followed. During the construction phase, utilizing a **BIM framework** is expected to provide valuable information, increasing efficiency and collaboration between the stakeholders while reducing the cost and the risks. BIM will also provide useful information during the lifespan of the building, allowing preventive maintenance and repairs to be implemented with minimum nuisance for the building's occupants and a comfortable indoor environment [13], [21]. When circular economy principles and BIM tools are applied from the early stages of a project in its design phase, they are able to provide useful information on how the different materials used can affect the reuse potential of the building. Circular economy and BIM tools are also beneficial during the disassemble phase of a building, allowing a larger percentage of materials, structures and components to be reused at the end of the useful lifetime [15]. The following diagram presents the design approach that supports the implementation of a circular economy in the building sector.

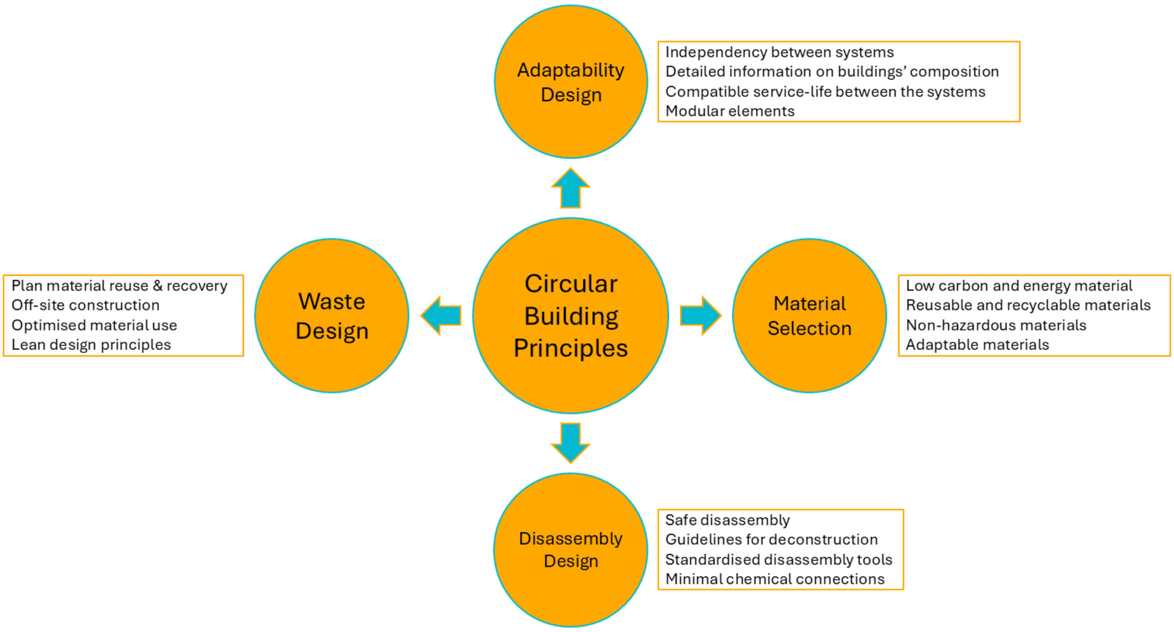

Figure 40: Circular buildings' design [13]

In order to assess the environmental impact and the use of resources in buildings, a commonly established method includes the implementation of the **life cycle assessment** (LCA). Studies have shown that the materials used can play a key role in the energy efficiency of the building accounting for 50% of the total CO_2 emissions, while there are cases where the materials played a much higher role, reaching 75% or even up to 90% of the total CO_2 emissions [22], [23], [24]. LCA could be conducted in various stages of the building. The life cycle stages of a building are described on Table 8 below. These stages are included in the LCA analysis for the buildings. It is worth noting that the method described on the European standard EN 15978 from CEN TC 350 could be applied to existing and new buildings as well as to refurbishment projects [22].

Any considerations regarding the future development of an existing building will be concerning the preservation, the renovation or the demolition and new construction. Preservation and demolition are not clearly described in EN 15978, although concerning the preservation the impact from the remaining use stage and the end of life or the impact from the previous stages could be included. When new buildings are assessed, the impact of the renovation should be allocated to "B5 – Refurbishment". This stage includes the impact in terms of production of new components in the building that will require material input, transportation and construction. Although the aforementioned standard includes the stages related to the end of life for the components that have to be replaced. Renovation is also included in the stage "B5 – Refurbishment" only if the renovation is planned for a future timeline. If the renovation is in progress, a new LCA should be made and in that case the materials and the processes are allocated to the production and construction process stage (A1 to A5) [22].

Production stage	
A1	Raw material supply
A2	Transport
A3	Manufacturing
Construction Process stage	
A4	Transport
A5	Construction, installation process
Use stage	
B1	Use
B2	Maintenance
B3	Repair
B4	Replacement
B5	Refurbishment
B6	Operational energy use
B7	Operational water use
End of Life stage	
C1	De-construction
C2	Transport
C3	Waste processing
C4	Disposal
Benefits and Loads beyond the system boundary	
D	Reuse, Recovery, Recycling potential

Table 8: Buildings' life cycle stages [22]

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3.3 INTEGRATED APPROACH IN EACH PILOT SITE

3.3.1 Danish pilot

3.3.1.1 LCA

The life cycle assessment quantifies the building's environmental footprint across its life stages, covering production, operational energy, component replacement, and end-of-life impacts to is evaluated against two emissions thresholds: the limit value specified by paragraph BR18 § 298 [25], which allows a maximum of 12.00 kg CO_2-eq./m²/yr. The climate impact must be measured in kg CO_2-equivalents per m² per year, calculated in accordance with DS/EN15978:2012, Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method [26]. The climate impact is calculated over a 50-year assessment period from the building's completion. EPDs allowed are made in accordance with ISO 14025.

Tech House's design incorporates both electricity and district heating systems to meet the energy demands of a commercial office environment while staying within regulated limits. The projected electricity consumption for the building is 5.90 kWh per square meter annually, and district heating requirements are estimated at 33.3 kWh per square meter. The energy model includes electricity supplied through the national grid, projected to decarbonize over time, and district heating, a widely used and acclaimed low-carbon option in Denmark. As per 2024 57% of all m^2 buildings are heated with district heating [27].

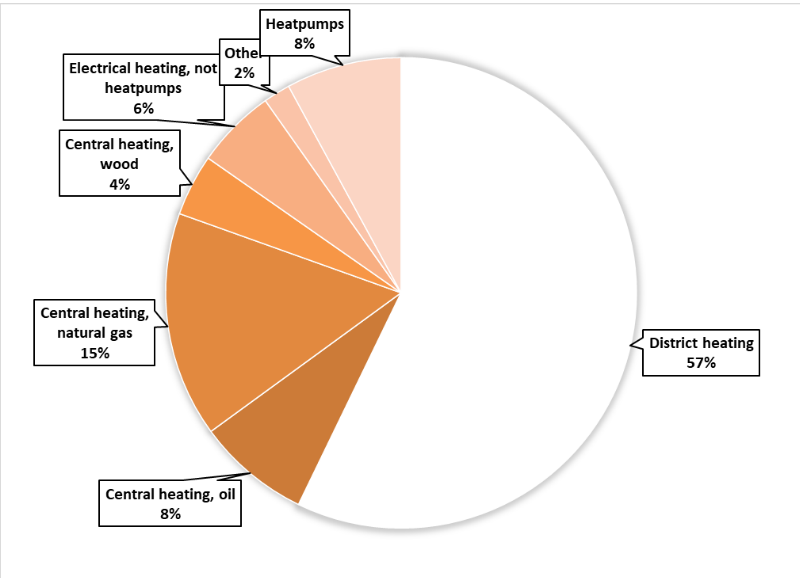

Figure 41: Distribution of heating sources in Denmark based on square meter of all building types, 2024 [27]

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By following these energy sources and consumption rates, the building ensures adherence to emission thresholds set by Danish regulations. The total calculated climate impact for Tech House is 11.46 kg CO_2-eq./m²/yr, just below the threshold for compliance with § 298 but not achieving the low-emission standard of § 297, suggesting possible areas for future refinement in terms of energy and material efficiency. The included life cycle stages are A1-A3. B4, B6, C3 and C4, see table below for further details.

LCA stages		Included in the analysis
Production stage		
A1	Raw material supply	Yes, (product EPD/generic EPD)
A2	Transport	Yes, (product EPD/generic EPD)
A3	Manufacturing	Yes, (product EPD/generic EPD)
Construction Process stage		
A4	Transport	No
A5	Construction, installation process	No
Use stage		
B1	Use	No
B2	Maintenance	No
B3	Repair	No
B4	Replacement	Yes, (product EPD/generic EPD)
B5	Refurbishment	No
B6	Operational energy use	Yes, (Simulated, with future energy mix)
B7	Operational water use	No
End of Life stage		
C1	De-construction	No
C2	Transport	No
C3	Waste processing	Yes, (product EPD/generic EPD)
C4	Disposal	Yes, (product EPD/generic EPD)
Benefits and Loads beyond the system boundary		
D	Reuse, Recovery, Recycling potential	No

Table 9: Buildings' life cycle stages [17] and the stages included in LCA of Danish demo

The climate impact assessment spans multiple stages in the building's life cycle. In the production phase (A1-3), impacts are calculated based on the extraction, manufacturing, and transport of construction materials, with data precision enhanced by the BIM-based quantity take-offs and EPDs for specific materials. The replacement phase (B4) includes the potential need for substituting certain materials or components, acknowledging the emissions associated with these replacements. The operational energy phase (B6) remains one of the most significant contributors to the building's long-term climate impact, where projections account for the Danish grid's gradual shift toward renewables and the environmental footprint of district heating. According to the Danish Energy Agency [28] the Danish CO_2 impact for the entire district heating system in 2018 where responsible for 7.8 Mt CO_2 eq. whereas the current projection for 2025 is 2.0 Mt CO_2 eq. and 0.5 Mt CO_2 eq. In 2030. In the final end-of-life stage (C3-4), emissions are calculated for building demolition, material waste processing, and disposal, with an emphasis on potential recycling and circularity principles to limit impact in these final stages. Module D: Potentials for reuse, recycling, and other forms of recovery, as per § 297, Subsection 2, are not included in the calculation. The reasoning is that potential impacts are difficult to regulate against, as future reuse, recycling and recovery is highly speculative. That said, current regulations in Denmark encourage voluntary analysis and evaluation of D-stages to support reuse, DfD, inbuilt flexibility, and other circular initiatives.

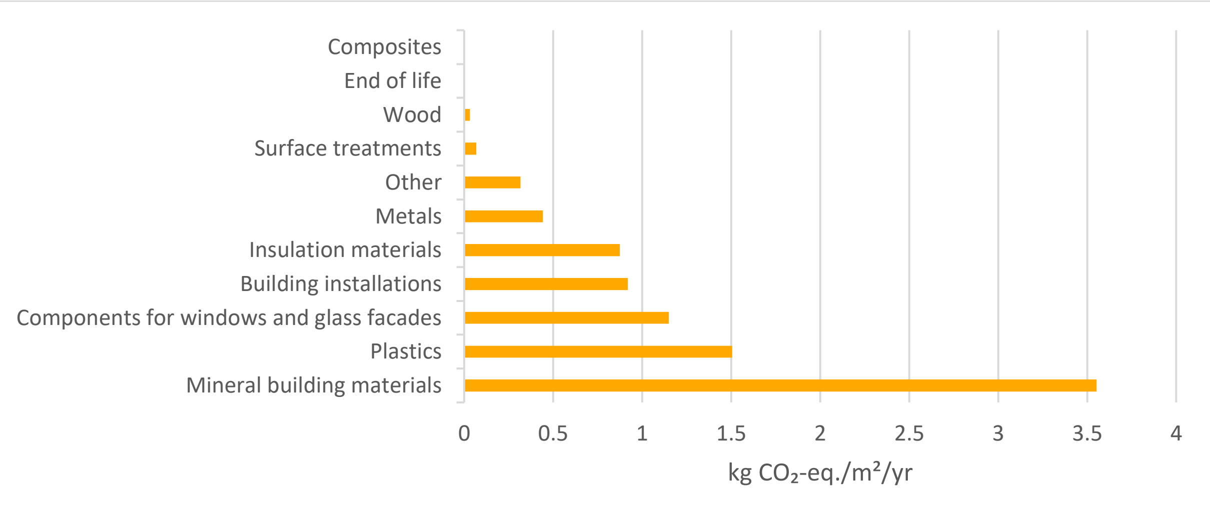

Figure 42: Climate impact sorted by material type (kg CO_2-eq./m²/yr over 50 yr)

The floor area and reference area used in the LCA provide a standard measurement framework, with a reference area setting a baseline for calculating emissions intensity per square meter. This metric directly informs the building's overall sustainability profile, allowing for comparison against regulatory and best-practice benchmarks.

While Tech House meets regulatory compliance requirements, it does not achieve the low-emission classification and thus presents an opportunity for further improvement.

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Refinements in material selection, such as opting for high-recycled-content materials that also promise high (thermal) performance or incorporating more climate-efficient renewable energy sources (solar cells) e.g. by balancing better CO_2 eq. (based on their EPD’s) and their projected efficiency built-in onsite than the current PVs can achieve could push its emissions profile closer to the low-emission target without growing the CO_2-budget. Additionally, the use of modular and flexible design elements may reduce the frequency of replacements and enhance end-of-life recycling, aligning with circular economy principles and future-ready building practices.

From Figure 43 its evident that the heavy building components, decks, and interior walls are responsible for a significant part of the total CO_2-budget. Since load-bearing elements are based on reinforced concrete, the large amount of CO_2 emissions spent to create and manufacture cement, and steel is directly associated with these parts of the building. On the other hand, heavy elements such as precast concrete tends to lead to long technical life span, which means that these elements are not expected to be worn down and substituted with a new element (b4). However, the top-layer of decks do need to be changed out over its lifetime, and this evidentially has an impact over the 50-year period. Worth noticing is that ventilation and cooling systems are assumed to live 50 years without full replacement. This is perhaps OK as one may assume that all parts will not be replaced all at once but handled over time with ongoing maintenance (B2), repair (B3) and refurbishment (B5). The problem is that the method exclude these stages and the full extent of the climate impacts cannot be seen in the results. HVAC systems collectively may have much higher CO_2-impacts when all stages are included. The HVAC systems are all modelled on Danish standard systems, meaning it's a methodological systemic issue that needs attention, rather than a failure in the model.

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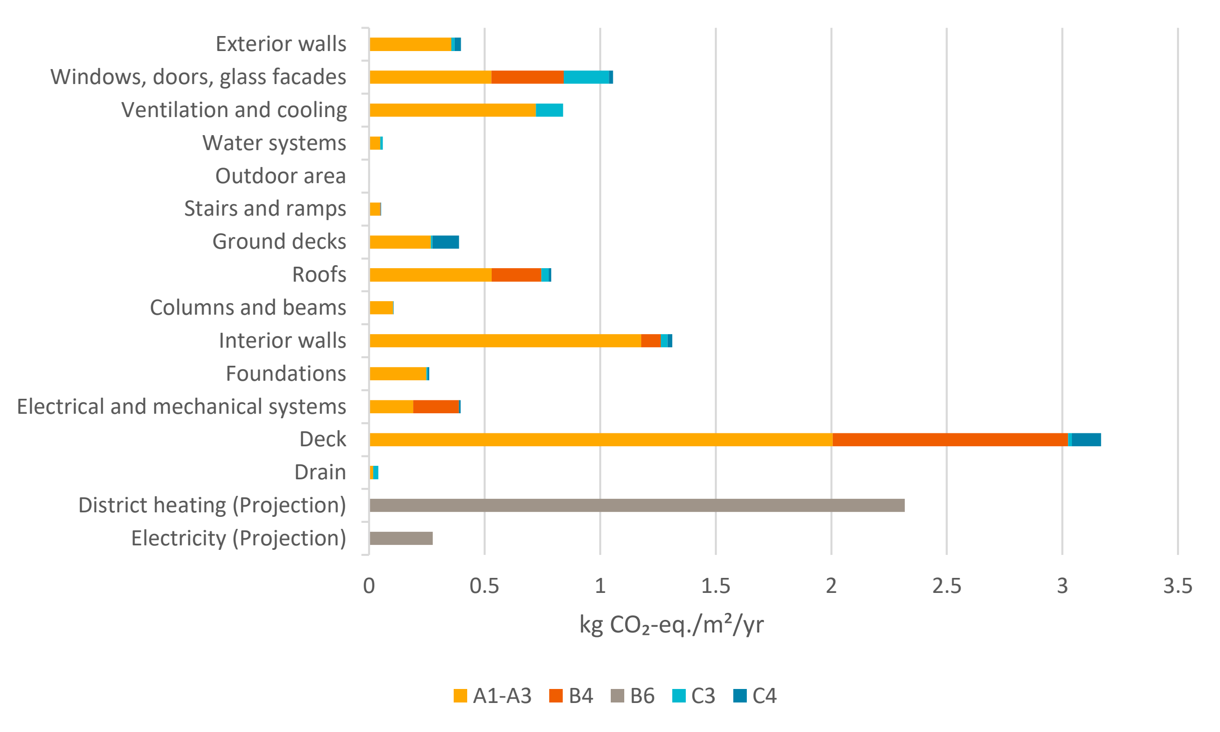

Figure 43: Climate impact sorted by building parts and systems (kg CO_2-eq./m²/yr over 50 yr)

The Tech House's LCA offers a comprehensive view of its environmental footprint, revealing the building's strengths in regulatory compliance while also identifying clear paths for enhancement. The integration of BIM-driven quantity take-offs and product-specific EPDs elevates the LCA's accuracy, grounding the assessment in real data and aligning with the precision and transparency goals of contemporary sustainable architecture.

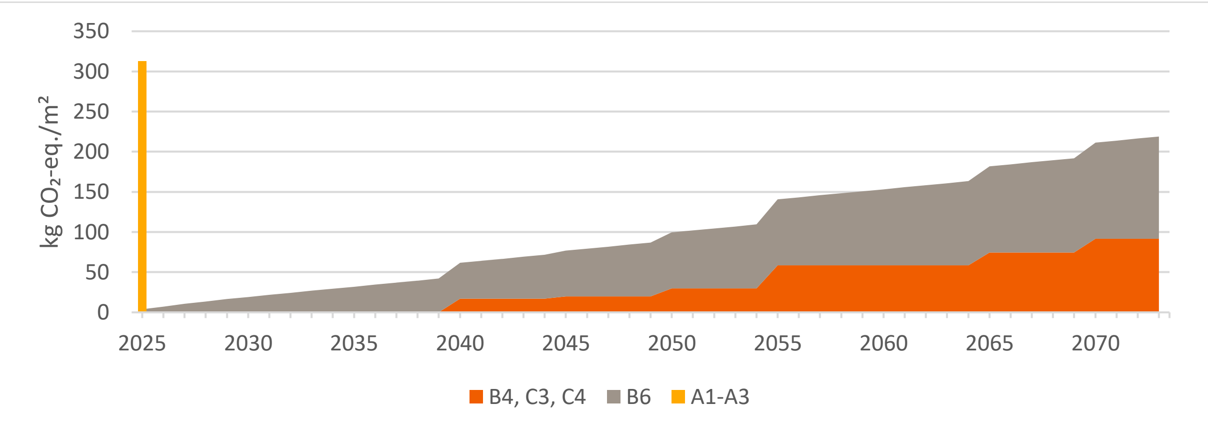

Figure 44: Climate impact over time (kg CO_2-eq./m² over 50 yr)

3.3.1.2 PV and Battery Sizing

The estimated annual generation for the DK pilot site is 54,296 kWh and the plant capacity is calculated at 54.62 kW. The inverter capacity is 52.5 kW with a storage capacity of 129 kWh. The plant configuration includes Heliene 96M475 panel, a Huawei Technologies Co., Ltd. Inverter (SUN2000-50KTL-C1 52.5 kW) and the necessary energy storage systems (Huawei Technologies Co., Ltd. LUNA2000-129KWH-2H1 129 kWh). The following figure (Figure 45) presents the plant visualization while Table 10 presents the rooftop characteristics.

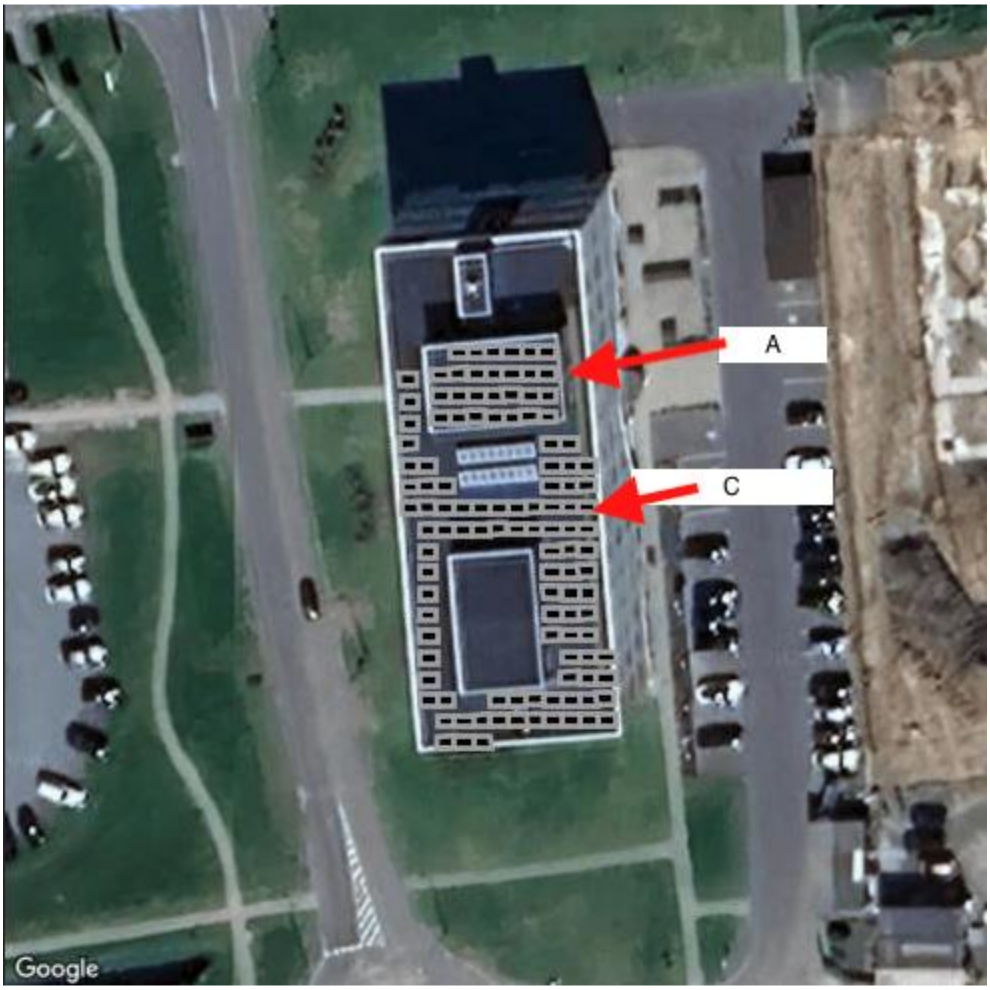

Figure 45: Plant Visualization and Rooftop Characteristics – south faced rows of panels at 9 degrees of inclination.

Rooftop Side	No. Panels	Useful Area	Shading	Orientation	Slope
A	27	67	0.0	Flat (0°)	0°
C	88	220	0.0	Flat (0°)	0°

Table 10: Rooftop characteristics. Rooftop Side C presents the largest flat rooftop side, while the rooftop side A presents a smaller, elevated part of the flat rooftop with panels to be placed on top of it.

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The PV plant is estimated to generate **54,296 kWh** per year. The peak generation is expected to be **6,400 kWh** and it is expected to be achieve in June. The minimum generation is expected to be **550 kWh** in December. The average production for this installation is calculated at **4,525 kWh**. The following image (Figure 46) prevents the monthly estimated consumption and the production balance.

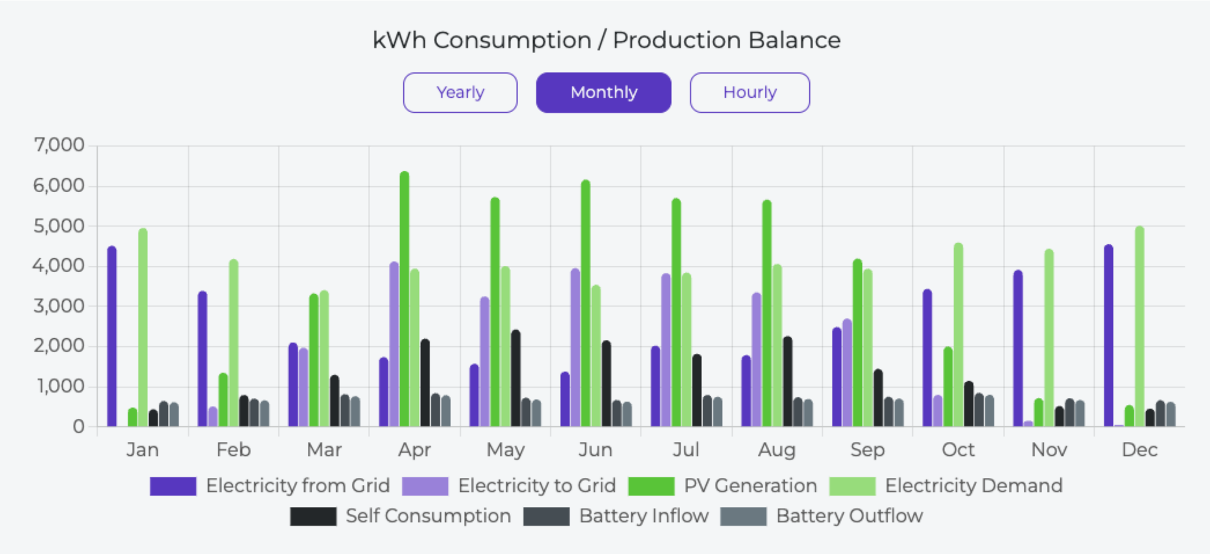

Figure 46: Plant Visualization and Rooftop Characteristics

The total investment for the described system is EUR 90,513 (incl. VAT) and the expected payback period is approximately 10 years. The energy storage system for the proposed system accounts for 33% of the total investment, followed by the cost of PV panels, accounting for 16% of the investment and the inverters (8% of the total investment). The expected savings on the electricity bill in a monthly basis are EUR 1,036. The following chart (Figure 47) depicts the investment breakdown and the feasibility of the investment, while the following table (Table 11) presents the description of each item, the relevant cost per item and the quantities for this project.

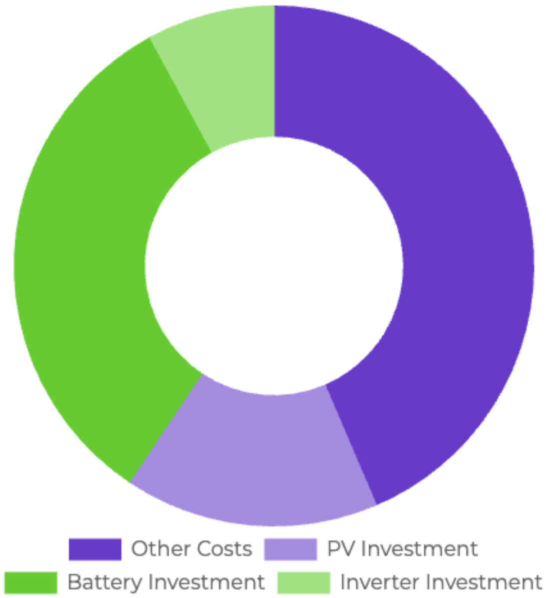

Figure 46: Investment Breakdown and Feasibility

Item Description	Quantity	Unit Price (EUR)	Total (EUR)
Procurement, transport and installation of PV Panels (Heliene 96M475)	115	105	12,075
Procurement, transport and installation of Inverters (Huawei Technologies Co., Ltd. SUN2000-50KTL-C1 52.5 kW)	1	5,861	5,861
Procurement, transport and installation of Batteries (Huawei Technologies Co., Ltd. LUNA2000-129KWH-2H1 129 kWh)	1	25,000	25,000
Other costs - Mounting system - Electrical circuits (cables, connectors, switch) - Other materials & miscellaneous	-	33,125	33,125
		Total Net	76,061
		Discount	0%
		Total Net w/ Discount	76,061
		VAT	19%
		Total Gross	90,513

Table 11: Itemised cost and quantities for the proposed project

3.3.2 Belgian pilot

LCA is not part of the Belgian demo, we have chosen to go for a **fully renewable (fossil-free) hybrid collective energy system with optimised annual global system performance** ('De Schipjes') and replication of the concept to 'Stijn Streuvels'. Energy efficiency and carbon-neutrality are thus the drivers in these designs. Moreover, cost-effectiveness is increased by minimizing both CAPEX (through optimal sizing, incorporating optimal control) and OPEX (through optimal control). System robustness is increased by going collective and going hybrid, including automated fault detection.

The **cost estimate** for the upgrade of the energy system and the installation of the hydronic switch for 'De Schipjes' (which is meant to be a living lab that should lead to a more targeted (and thus cost-effective) version for replication) is set at € 101.514,46 excluding VAT and exclusive the costs for the update of the BMS and the execution of the extension of the energy cabin.

However, circular principles and considerations for a positive effective of the used materials, are used as guidelines for the 'Stijn Streuvels' renovation. For instance:

- for 'Stijn Streuvels' the air-water heat pumps use R290 as working fluid, which is a natural gas.
- The existing roof tiles are being re-used when renovating the sloped roofs.

3.3.3 Hungarian pilot

A Life Cycle assessment is in progress for the Hungarian demo site.

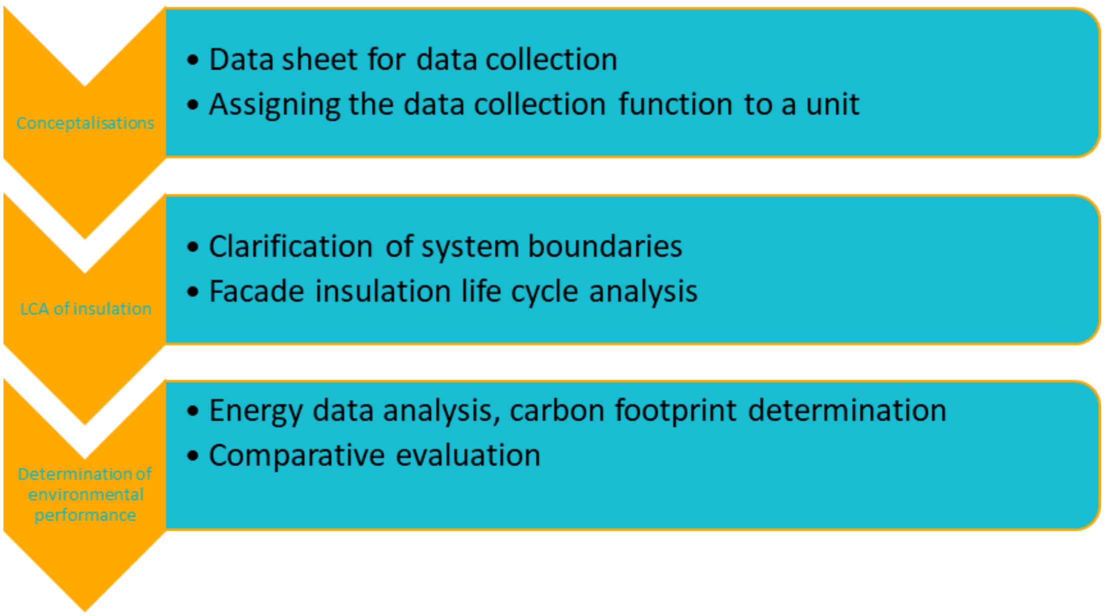

Figure 47: Life cycle assessment process

The purpose of LCA studies is to determine how building renovation reduces environmental impacts and the cost of changing carbon dioxide emissions.

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To do this, we first examine the effects of insulation and, later, the replacement of windows and doors and mechanical renovation. We will aggregate these results and determine the loads per square meter of floor area. The life cycle cost is determined in the same order, and the cost estimate related to the reduction of carbon dioxide emissions expected after renovation is made.

The data we received from the manufacturer about the weber.therm.circle External Thermal Insulation Composite System (ETICS):

- the data of the themal insulation , including the layer order,
- the technical description of the components,
- the EPD of the component (weber-therm 302),
- and the transport distances, form the crucial foundation for our environmental impact assessment.

The layers of weber.therm.circle ETICS system:

- existing masonry and plastered walls
- 20 cm thermal insulation board, fixed with disc dowels (10pcs/m^2) without gluing (weber.therm MW040)
- 8-12 mm base plaster (weber.therm Armadura base), embedded fiberglass separation mesh (weber.therm 310)
- 5-8 mm light reinforcing plaster (weber.therm 302), embedded fiberglass separation mesh (weber.therm 310)
- mineral top layer (weber.therm 307)

Additional data collection was required for the analysis. To achieve this, we utilised the SimaPro 7.2 database and EPDs with similar functions and technical parameters.

The system boundary extends from the cradle to the grave and is a critical assessment aspect. From a practical standpoint, we also examined sections A1-A3, A4, A5, and C and D of the MSZ EN 15804 standard, ensuring a comprehensive evaluation of the insulation's environmental impact.

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	A1-A3	A4	A5	B1	C1	C2	C3	C4	D	Total
thin plaster- weberpastopDR	X	X	X		X	X	X	X	X	X
weberterm302	X	X	X		X	X		X	X	X
glass mesh - weberterm310	X	X	X							X
weber.therm armadura base	X	X	X		X	X		X	X	X
glass mesh - weberterm310	X	X	X							X
mineral wool insulation - PR	X	X	X			X		X		X
total /m2 Surface	X	X	X		X	X	X	X	X	X

Figure 48: The investigated life cycle stages

The investigation was carried out in several phases.

- In the first step, the environmental effects of the facade insulation per square meter as a functional unit are assessed.
- In the second step, the environmental impact of the insulation is determined per square meter of the floor area of the building; in the first step, the embodied carbon content is expressed in CO_2 equivalents (GWP – Global Warming Potential). In the future, the investigation will be extended to several other impact categories for example: Abiatic Deplation Potential (ADPfossil), Acidification Potential (AP), Osone Deplation Potential (ODP). For this, it was necessary to determine the entire surface to be insulated and then the total floor area of the 3-story building to determine the environmental effects per square meter of floor space and the environmental load per apartment.
- The Next task was determining the building's energy consumption and carbon footprint. We achieved this by analysing time series data on the building's energy consumption, which allowed us to calculate the associated carbon emissions.

GWP determination per square meter of the insulation

layers\ \life cycle stages	**A1-A3**	**A4**	**A5**	**B1**	**C1**	**C2**	**C3**	**C4**	**D**	**Total**
weberpastopDRY	0,8216	0,05538	0,03224	0	0,0598	0,02075	0,01971	0,00437	0,00089	1,01474
weberterm302	3,86688	0,1	0,43	1,34064	0,02736	0,05581	0	0,14866	-0,16781	5,8078
weberterm310	0,15248	0,00737	0,00196							0,16181
weber.therm armadura base	5,075	0,14	0,595	-1,8375	0,00375	0,765	0	0,2	-0,23	4,71125
weberther 310	0,15248	0,00737	0,00196							0,16181
mineral wool	15,4869	0,28849	1,38933	0	0	0,06265	0	0,21011	0,17404	17,6115
GWP/ 1m²	25,5553	0,59862	2,45048	-0,4969	0,09091	0,90421	0,01971	0,56313	-0,22288	**29,4689**

Table 12: GWP determination per square meter of the insulation

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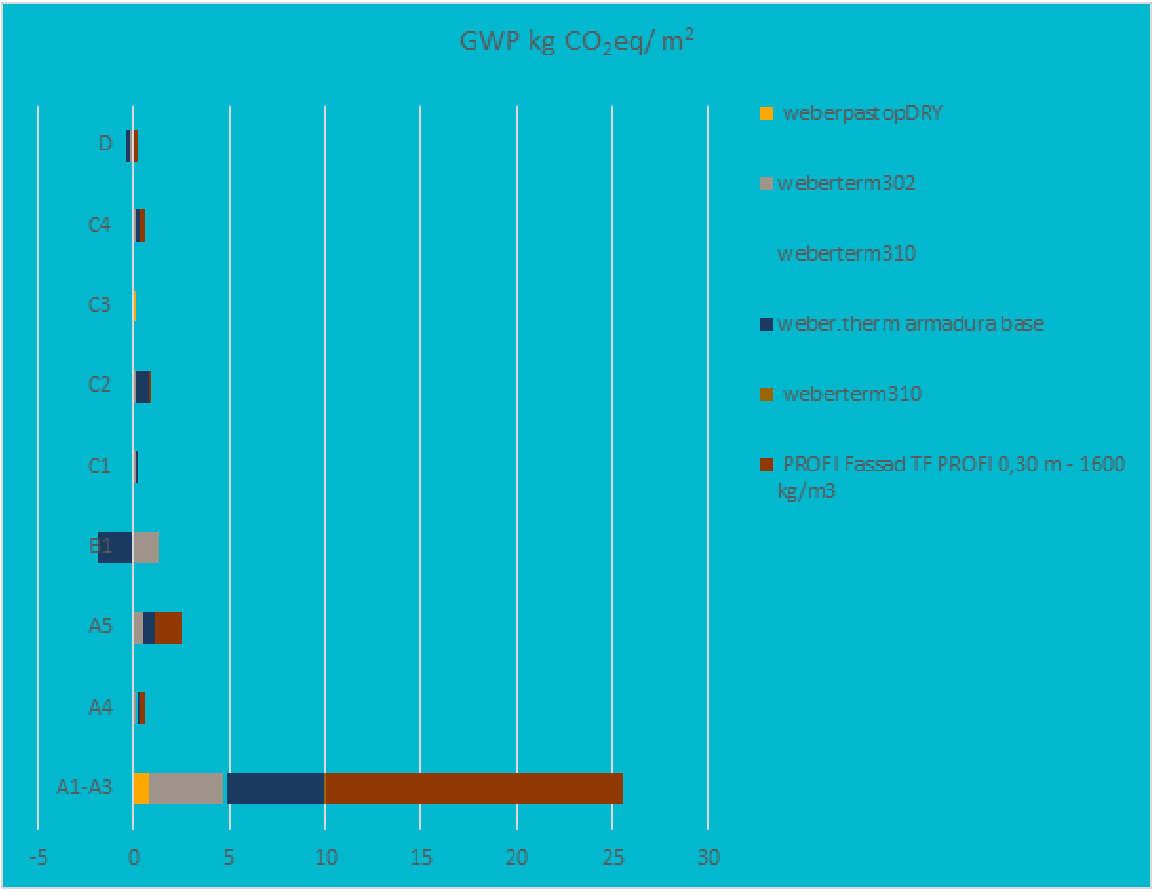

Figure 49: GWP values of insulation per 1 m^2 floor area by layers

The greenhouse effect of insulation, as the embedded carbon content per 1 m^2 of the building's floor area: 43.71367 kg CO_2 eq.

In conclusion, the analysis showed that more than 50% of the greenhouse effect of the insulation is caused by the 30 cm layer thickness of mineral wool. By optimising the layer thickness of the insulation to 20 cm, the GWP value of the A1-A3 section can be reduced by 33%, and if domestically produced insulation material is used, this results in a further reduction because the greenhouse effect associated with transportation is also reduced by a fifth. The reduction in layer thickness results in a minimal increase in carbon dioxide in the use phase. If Webertherm 302 could also be replaced with a domestically produced product, a total carbon dioxide saving of 35-40% can be achieved.

Data of Energy consumption

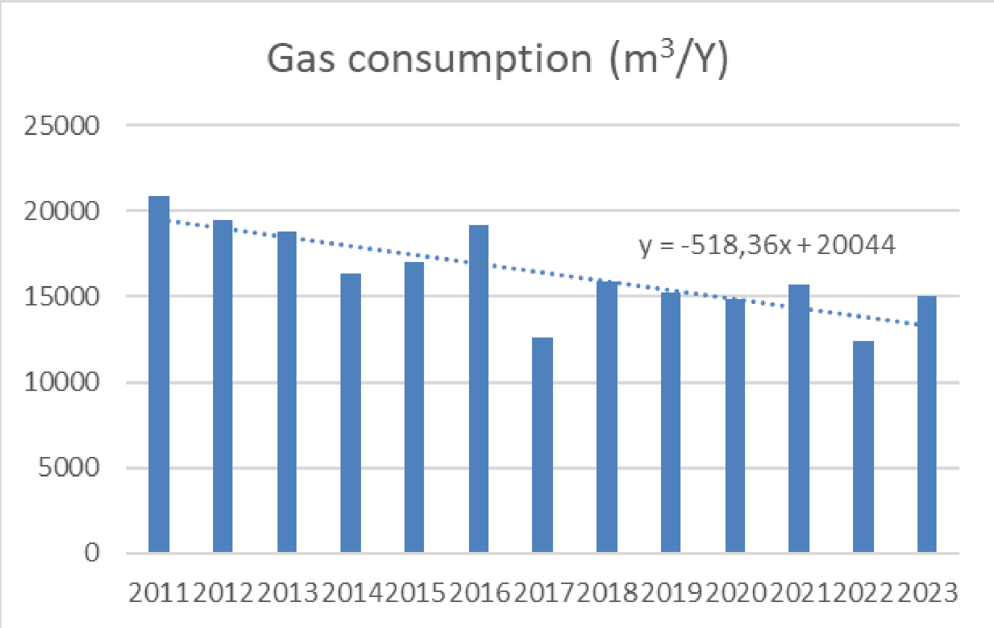

Figure 50: Gas consumption of the building (Source:Gas Bill of building)

The drastic increase in gas prices after 2020 caused a decrease in consumption.

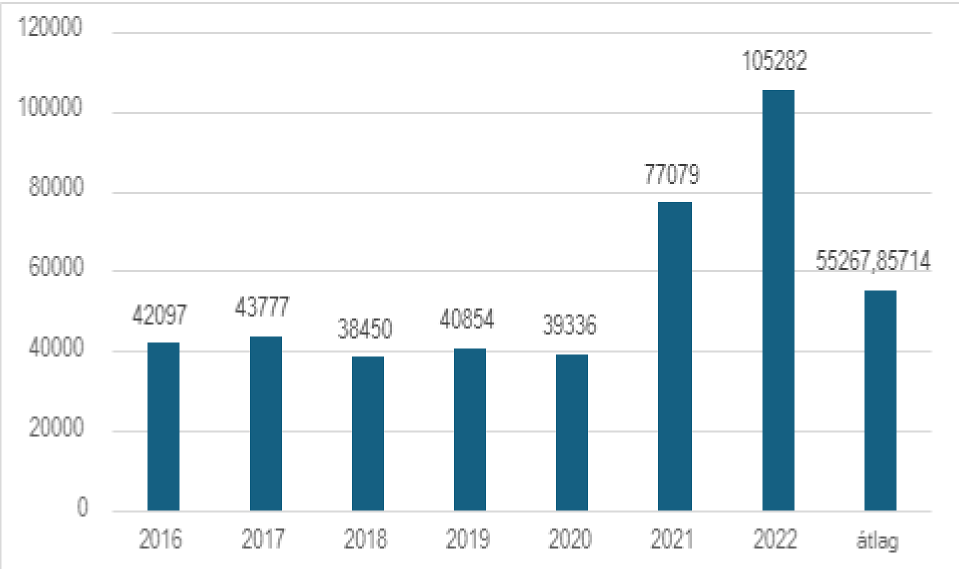

Figure 51: Price of electricity consumption HUF/kWh,Y (Source: electricity bill of the building)

In 2022, the high value because of the change in electricity price. Electricity rates in universal service for residential customers from August 1, 2022. Reduced pricing (reduced utility price) 42,456 HUF/kWh, residential market price: 70,104 HUF/kWh (ELMÜ Kft).

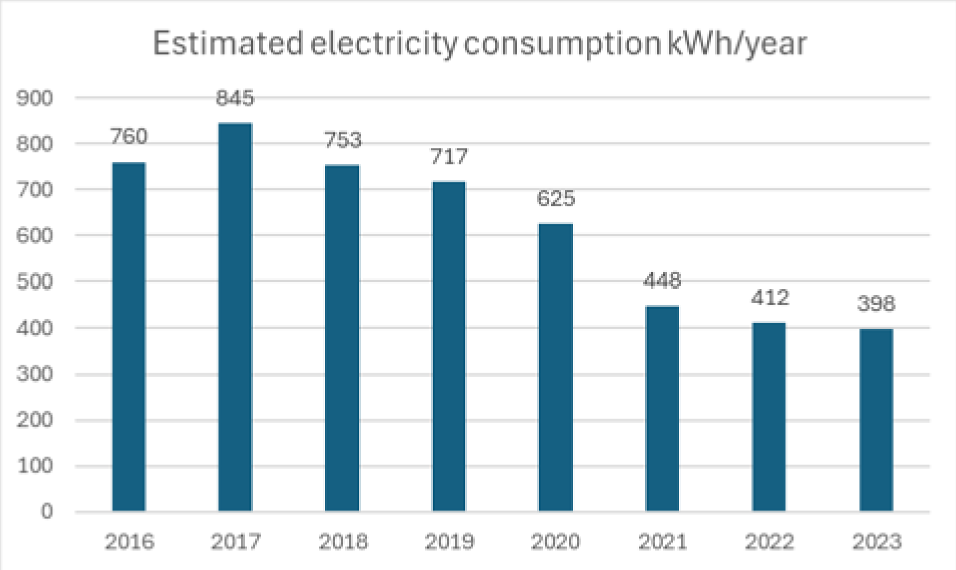

Figure 52: Estimated electricity consumption kWh/year (Source: electricity bill of the building)

Electricity consumption decreased due to price changes.

We calculated the value of electricity and gas consumption per square meter. We determined the carbon footprint of the entire building based on the carbon footprint of 0.0712 kg CO_2 eq. per 1 MJ, but 1m^3 gas equivalent 34.1 MJ, so 2,42792 kg CO_2 eq of 1 m^3 of gas carbon footprint, and 0.417 kg CO_2 eq. of 1 kWh of electricity. Considered floor area: 795,6 m^2

Carbon footprint of gas consumption: 50.09504 kg CO_2eq./m^2, and 39855 kg CO_2eq./year.
The carbon footprint of electricity consumption: 0,2197 kg CO_2eq./m^2 and 174,82 kg CO_2eq./year.

Carbon footprint of energy consumption (gas+electricity) of the investigated building: **40.03 tons CO_2 eq./year**

The analysis examined the energy consumption and the associated greenhouse gas emissions during the use of the building, as a carbon footprint, based on historical data, which is a starting point for determining the percentage of energy savings and greenhouse gas reductions achievable with renovation.

3.3.4 Greek pilot

With the electrification of PSYCTOTHERM's Heat Pump, through the electricity generated by the Bifacial PV's and heating supply from hybrid system of biomass boiler and solar panels, carbon emissions will be drastically reduced. The cooling supply that will be provided by the Absorption Chiller installed in the Energy Center will also contribute to this goal. The overall efficiency increases the Demo Site's thermal network along with data availability from the smart sensors installed in the student's dorms, integrated with an upgraded BMS system will

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satisfy the heating and energy demand more smoothly. Optimal sizing of equipment will be a key factor in reducing the cost of investment.

Within the SEEDS project an innovative 10 kW PV with a tracking reflection system will be developed and installed in the nearby field. The PV panels will be installed at a fixed angle and south orientation. The trackers of the reflection system will move/tilt in response to smart algorithms that consider the position of the sun, radiation, weather forecast etc. The reflection system will be positioned in such a way as to maximize the amount of sunlight reflected onto the PV panels and will capture and redirect more sunlight onto the modules, particularly during times of lower sunlight intensity, such as during the morning and evening hours, or on cloudy days. Additionally, a multi-source (air, geothermal, solar thermal) heat pump (HP) with a capacity of 70 kW will also be installed in the building's basement for heating and cooling purposes along with fan coils in 20 rooms of the building. The produced photovoltaic energy will be utilized to supply the heat pump unit and cover at least 25% of its energy needs.

Life Cycle Cost Analysis (LCCA) is an economic method to evaluate projects, according to which all costs resulting from the initial investment, operation, maintenance of each project are considered potentially significant and contribute to the final decisions about the implementation of the energy saving measures. Therefore, it is an important tool for each administrative unit that prioritizes the proposed projects, and thus significantly determines the business plans and plans of an administration. Additionally, the analysis provides the necessary information to the investor in order to be able to evaluate the economic efficiency of each proposed investment, taking into account the reduced energy costs and the other economic effects during the lifecycle of the project[2].

In order to carry out the LCCA analysis **two different scenarios** were performed. In the first scenario the installation of the heat pump unit is considered, while in the second scenario the installation of the PV system is added to the calculations. Additionally, some assumptions were made, i.e. the discount rate equals 3%, annual change in energy price 0.5%, project lifespan 25 years and VAT is excluded from all costs and benefits[3]. The costs of electricity, heating oil and biomass are the average values calculated based on literature research[4]. The following tables summarize the parameters considered in the two scenarios of the life cycle assessment.

[2] "Energy Audits", Greek Ministry of Environment and Energy. (accessed Oct. 24, 2024)
[3] "Energy Performance Plan for Regional and Municipal Buildings", Greek Ministry of Environment and Energy. (accessed Oct. 24, 2024)
[4] Greek Technical Chamber TOTEE 20701-1 Technical Guidelines on Buildings' Energy Performance 2017.

Discount Rate	3.00%	3.00%
Annual Change in Energy Price	0.50%	0.50%
Oil Cost [€/kWh]	0.1250	0.1250
Natural Gas Cost [€/kWh]		
Cost of Electricity without PV [€/kWh]	0.1100	0.1100
PV - Reflection system	NO	YES
Concurrency Factor	85.00%	85.00%
Cost of electricity with PV-reflector [€/kWh]		0.0000
Biomass cost [€/kWh]	0.1600	0.1600
District heating cost from PPC [€/kWh]		
Years of Evaluation	25	25
Years of Analysis	24	24

Table 13: Input data considered in the two scenarios of LCCA; Scenario 1 excludes the PV-reflection system while in Scenario 2 the PV-reflection system is considered

The CO_2 emissions ($kgCO_2/kWh$) per fuel type are given in Table 11[3], while for the calculation of costs, the relevant assumptions of Table 12 from the National Energy and Climate Plan are used, with linear interpolation for the intervening years[2].

Type of energy source	CO_2 emissions per kWh energy ($kgCO_2/kWh$)
Natural gas	0.196
Heating oil	0.264
Electrical energy	0.989
Liquefied petroleum gas (LPG)	0.238
Biomass	---
District heating from PPC	0.347

Table 14: CO_2 emissions coefficient[3]

	2016	2020	2025	2030	2035	2040
Carbon Emissions Allowances Price [€2016/kg CO_2,eq]	7.76	15.52	23.28	34.66	43.45	51.73

Table 15: Predictions for the carbon emissions allowances price[2]

The following step is to insert the data related to cost categories in order to calculate the total cashflows of the investment for each scenario. The results lead to the calculation of the Net Present Value (NPV) of the investment for each scenario. In Figure 53 the cost categories are presented for Scenario 1 (heat pump installation) and Scenario 2 (heat pump and PV system installation). It is worth mentioning that the total investment cost is increased when considering more interventions. The annual energy consumption for the baseline scenario (current situation) per fuel type has been filled in with the data provided by Democritus University of Thrace and are included in the previous chapter.

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Cost Categories	Year	0	0
Investment Cost			
	Investment Cost	150,000.00 €	190,000.00 €
Annual Energy Consumption baseline scenario per fuel type			
	Heating oil	215,000.00 kWh	215,000.00 kWh
	Natural gas		
	Electricity	139,468.00 kWh	139,468.00 kWh
	Biomass	170,976.00 kWh	170,976.00 kWh
	District Heating from PPC		
Annual Cost in the baseline scenario			
	Energy Cost	69,572.64 €	69,572.64 €
	Annual Operational Cost		
	Annual Maintenance Cost	1,000.00 €	1,000.00 €
	Annual Cost of CO2 emissions	2,643.94 €	2,643.94 €
Annual Energy Consumption after energy upgrade scenario per fuel type			
	Heating oil	38,600.00 kWh	38,600.00 kWh
	Natural gas		
	Electricity	189,868.00 kWh	139,468.00 kWh
	Biomass	170,976.00 kWh	170,976.00 kWh
	District Heating from PPC		
Annual Cost after the energy upgrade scenario			
	Energy Cost	53,066.64 €	32,181.16 €
	Annual Operational Cost		
	Annual Maintenance Cost	500.00 €	500.00 €
	Annual Cost of CO2 emissions	520.89 €	419.36 €
Total Cash Flow		150,000.00 €	190,000.00 €

Figure 53: Cost categories for both Scenarios

Below the benefit categories are presented considering the two different scenarios. More specifically, the annual benefit from the increase in domestic value added is calculated based on specific factors, given by the Hellenic Ministry of Environment and Energy, as shown in the table below[2]. The annual benefit from other externalities - non-energy benefits is considered negligible and is not included in the calculations.

Type of energy intervention	Factors that impact the domestic value added per 1 Euro (€) investment cost (€)
Heat pump for heating of a building, built between 1981 and 2010	0.066
PV system	0.027

Table 16: Factors that quantify the energy interventions' impact on the domestic value added[2]

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Benefit Categories		Year 0	Year 0
Financial and Macroeconomic Benefits			
	Residual value		
	Energy savings	16,506.00 €	37,391.48 €
	Energy savings calculating the increase in energy prices	16,506.00 €	37,391.48 €
	Difference between Operational Cost and Maintenance Cost	500.00 €	500.00 €
	Difference in CO2 emissions cost	2,123.05 €	2,224.59 €
	Annual benefit from other externalities - non-energy benefits		
	Annual benefit from the increase in domestic value added	9,900.00 €	10,980.00 €
Total Cash Flows		45,535.05 €	88,487.55 €

Figure 54: Benefit categories for both Scenarios

In order to assess the profitability of the project a fundamental metric is used, namely the Net Present Value (NPV). From the calculations above the Net Present Value (NPV) is computed for both scenarios, as shown in the following figures:

Internal Rate of Return	44.68%	88.17%
Present Cost	150,000 €	190,000 €
Present Value of Benefits	885,565 €	1,678,810 €
Benefit/Cost Ratio	5.90	8.84
Repayment Period	3.29	2.15
Discounted Payback Period	3.50	2.25
Net Present Value (NPV)	735,565 €	1,488,810 €

Figure 55: Net Present Value for both Scenarios

For **both scenarios the NPV is positive**, which indicates that the projected net cash flows generated by the project for a period of 25 years, is positive, the earnings exceed the anticipated costs and therefore **the investment is profitable**. The higher the NPV is, the more profitable the project is. The second case study, which combines the heat pump and the PV system, which will be implemented in the Greek pilot site is the most sustainable scenario.

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3.3.5 Slovenian pilot

Out of the 5 locations, we have decided to renovate the existing HVAC system at three of them with the aim of increasing the share of renewable energy sources. At the same time, we want to enhance energy efficiency at these locations and reduce carbon emissions. The system will be gradually optimized based on the experiences gathered from the implemented models, and it will improve from location to location.

Petrol d.d. also strives to operate in the field of circular economy. While the project may have limited opportunities for this, we will try to identify where these principles can be applied. The greatest potential is seen in the selection of materials or equipment produced from recycled materials and considering their recycling or reuse after the end of their life cycle.

The costs for the project solution amount to 100.000,00 € excluding VAT, while the implementation costs are estimated at 600.000,00 € excluding VAT and excluding the costs for the solar power system and battery storage.

LCA is not part of the Slovenian demo site.

4 CONCLUSIONS

The aim of this deliverable is to present the current status of the selected demo sites (construction and renovation), their features and the technologies that are currently included and used in each demo site. In addition to this, the integrated circular design and the cost assessment was described in this deliverable.

An overview of each site is provided as a part of this deliverable. For the construction site this includes the design and the ambition for the construction site whereas for the renovation sites the overview includes the current status, the methodology used for the assessment of each site and a detailed technical analysis. The SRI score is included for the relevant demo sites along with the evaluation that allows to identify potential areas of improvement and when needed a foreseen SRI score that will take into account the potential improvements was calculated.

Concerning the integrated approach in each demo site, the circular principles and considerations for a positive and effective use of materials were described. Where applicable, a life cycle assessment was conducted along with the relevant cost assessment scenarios.

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